Application of Ultra Smart Textiles in Sports Wear and Garments

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1.1 Acknowledgements

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Humdard University (Head Textile Department) to provide us the contacts of people are working with this material. We would like extend our warmest thanks to Mr. Naeem (Technical Director) Mr. Shahid Razzaq (General Manager) Faisal Spinning Mills Ltd, Sindh Pakistan; they give us concepts of fiber behavior during spinning process and effect of atmosphere on fiber and yarn properties. Here we cannot forget our respectable Professor Mr. Heikki Mattila, he support us on every moments and very helpful in every problem those we got during working on this project.

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1.3 Abstract

Smart textiles especially Phase Change Materials (PCMs) are getting attention because these materials can provide regulation of wearer’s body climate and provide comfort in the temperature fluctuations during the physical activity like sports. These materials have the advantage of latent heat energy storage that can absorb and release high amount of energy over a narrow temperature range around the human’s body temperature to provide thermal comfort. Phase Change Materials (PCMs) absorb energy during the heating process as phase change takes place and release energy to the surroundings during the reverse cooling process. The types of phase change materials that are suitable for sports applications are hydrated inorganic salts, linear long chain hydrocarbons, Poly Ethylene Glycol (PEG). The concept of thermal comfort and working of PCMs in the textiles garments are important for determining the functionality of PCMs. Phase Change materials are micro capsulated in the shells by “Situ polymerization technique” before application to sportswear and garments. The PCMs microcapsules are incorporated in the sportswear and garments by fiber technology, lamination, foaming and coating. The testing of clothing containing micro capsulated PCMs is discussed after the incorporation of PCMs in textiles. Quality parameters that are key for getting good results are mentioned i.e. particle size, thermal conductivity, fire hazard treatment, durability and performance of micro capsulated PCMs and clothing. In the last section findings, suggestions and conclusion are discussed.
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Chapter 1

1.4 Introduction

The consumption of the textile fibers in the sports is increasing tremendously every year. In one analysis made by David Rigby Associates in 2002 that the consumption of Textiles for sport increased from 841000 tons in 1995 to 1153000 in 2005 and the forecast made for year 2010 is projected to be around 1382000 tons. This rapid growth is due to the number of social factors like increased leisure time, growing of indoor and outdoor facilities, increased attention towards health and well being, ever increasing pursuit of working population for outside home activities. The sports sector is not only resulted in market diversification for new fibrous materials but also lifted the textile science and technology which is going to be in par with other high technology industrial sectors. New technology development, thermo regulated performance, quality, design, more comfortable and reliable products, more fragmented niche markets and increased customer expectations are some of the key drivers for the progress of this industrial sectors.

Fundamental laws and principles are employed in manufacturing of the sportswear and garments. Fiber and fabrics that contains automatic environment acclimatizing properties are getting more and more attention and employed in textiles. One of the smart textile materials which have automatic acclimatizing properties used in textiles is “Phase Change Materials”. Phase Change Materials are working on the principle “Phase Change” the process of changing from one physical state to another i.e. from solid to liquid and vice versa are suitable for textiles. The technology for application of micro capsulated phase change materials for thermal storage in textiles was developed in 1980s under NASA research programmers. The original intension was to provide thermal comfort for the “astronaut’s space suits” in the extreme weather conditions especially temperature fluctuations in space. After the space application, PCM incorporated textiles started getting marketing part in the consumer applications especially sports and garments. (S.Mondal, 2007)

1.5 Smart Textiles

‘Smart Textiles’ is itself a very vast field. If we want to explain the whole Smart Textile, it may take such a long period of time and may not be covered completely, because this field is under development. Many multinational companies and groups are spending millions of dollars in Research and Development.
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Smart Textiles are such structures or materials which can sense the environmental conditions and responds it or stimuli, especially from the chemical, mechanical and electrical sources. It is not a fiction story anymore, because there are several products already available in the market, for example, shape memory materials, self-cleaning carpets and suits etc.

In the manner of reaction, smart textiles are mainly divided into the following classification.

1.5.1 Passive Smart Textiles:
Are those textile materials, can be only sense surrounding conditions or stimuli.

1.5.2 Active Smart Textiles:
Textile structures those can not only sense but also reacts the surrounding conditions.

1.5.3 Very Smart Textiles:
These materials can sense, react and adapt themselves according to the environment conditions.

1.5.4 Intelligent Textiles:
These materials can respond to perform actions in a pre-programmed manner. Here is necessary to explain the Intelligent Textiles with an example.

Basically, these materials are developed to be able to sense that what is happening with the wearer. If the heart rate drops unexpectedly of the wearer, then the information is sent to the paramedics for description automatically.

![Figure 1: Working Principal of Intelligent Textiles](image-url)
1.6 Background:
The background of textile fibers is based on thousands of years, when the revolutionary change came into humanity from the animal skin to first fabric use. After that enormous changes come in textiles. But most importantly past 50 years are the period of most revolutionary changing period in textile and fibers.

Many factors are involved to raise this revolution. Most common example of these factors are warfare, family life, health and safety, wealth and social status of owner. Here we want to prefer those fabrics, which are used for multifunctional purposes, such as fashion and environmental protection, rain ware or those fabrics that are providing the resistance from threats, like ballistics, chemical and flame.

These all are passive systems as described before they can only sense. But we are focusing on those structures, which can not only sense but also react to environment stimuli, like magnetic, electric, chemical or mechanical. Basically this system is the best combination of ‘Textile’ and ‘Information Industry’.

Most of the innovations regarding ‘Smart Textile’ in last 50 years were only for military purpose, such as bullet resistant armor and chemical protective clothing. There are naturally many more applications of smart textile than those applied to military and civilian police, firemen and emergency responders, mountain climbers, sports persons, businessmen with wearable micro computers, and medical staff. They all can get benefits from this revolution in textile.

1.7 Objectives & Goals

1. We want to do research and development in ultra smart textiles such as phase change materials, shape memory materials and chromic materials.

2. Applications of ultra smart textiles in the field of sportswear and garments according to the needs and expectations of the customer.

3. Discussion and implementation of quality aspects such as quality control and quality management tools during the design and development stage of product to get customer satisfaction.

4. The sustainability of the developed product with respect to the environment friendly, economical and socially acceptance will be discussed during the product development and product life cycle stage. The disposal or the recycling of the product or the parts of product will also be considered at this stage.
1.8 Limitations

The research focuses on Research and Development process of Ultra Smart Textiles (PCM) in sportswear and garments. This paper based on research because to describe Ultra Smart Textiles practically need heavy investment for apparatus and row material. Ultra Smart Textile is in development process, and still many important achievements are hidden from us. We tried our best to describe row materials and method of application. But we cannot describe the testing methods and standards for PCM textiles, because there are no any standards for testing. However, our written supplier selection process is generally used by the research institutions and product development companies.

1.9 Outline

Chapter 1

This chapter presents the introduction of Smart Textiles, background of the topic, research objectives, limitation of our work and methodology, which present our research approach to collect data and research questions.

Chapter 2

This chapter represents the framework of row material, testing methods, manufacturing of PCM, finishes, quality issues, applications and modifications.

Chapter 3

This section is comprised of our findings and recommendations given to improve the existing process of manufacturing. We further discuss the topic and conclude.

1.10 Methodology

Personal interviews of product development managers used to answer the research questions and information obtained upon their company process. Emails and telephonic interviews of Professors provided us detailed information on manufacturing, finishing and testing process in general and particularly concerned research organizations. Empirical data and inductive approach used to design the whole selection process. Books on Intelligent Textiles and product development are used to
understand the issues included in the thesis. The factors influence the end user application and modification.

Chapter 2

2.1 Phase Change Materials for Sportswear and Garments

2.1.1 Phase Change Materials
Phase Change Material (PCM) that has the inherent property of latent heat that can be stored or released from a material over a narrow temperature range. Phase Change Material has the ability to change their state over a narrow temperature range. These materials absorbs energy (latent heat) during the heating process as phase change state takes place and release energy (latent heat) to the environment in the phase change range during a reverse cooling process. (S.Mondal, 2007)

2.1.2 Phase Change Process
Thermal energy storage (TES) is critical for the efficient utilization of the thermal energy. There are four alternatives for thermal energy storage. Alternatives are latent heat utilization, sensible heat utilization, utilization of heat of dilution and utilization of reversible chemical heat. Matter or materials exist in solid, liquid, gas and plasma state. Phase change is the process in which material is changed from one state to another. Mostly common phase change kinds are (I) solid to liquid, (II) liquid to gas, (III) solid to gas and (IV) solid to solid. In the phase change process heat is absorbed or released. The amount of heat that is released or absorbed during the phase change process is called latent heat. For manufacturing of heat storage and thermo regulated sportswear Phase Change Materials (PCM) having solid to liquid or from liquid to solid states are mostly suitable. (S.Mondal, 2007)

The techniques of heat transfer are strongly dependent on the phase of substances involved in the heat transfer processes. For solid substances conduction is the principal way of heat transfer while in the liquids convection is predominates. So the principle of phase change from solid to liquid and vice versa is practicable for the application of Phase Change Materials in sportswear. (S.Mondal, 2007)

Latent heat storage is the efficient method than sensible heat storage because it gives much high storage density with the narrow temperature difference between storing and
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releasing heat. During the heating process the PCM absorbs heat from the surrounding and PCM changes state from solid to liquid while its temperature increases constantly. During the cooling process PCM releases heat to the surrounding environment and PCM changes state from liquid to solid and its temperature decrease continuously. PCM as compared to the normal materials absorbs higher energy during the phase change process. For example paraffin absorbs 200 kJ/kg of heat energy as it goes melting process. Phase change materials repeatedly converted from solid to liquid and liquid to solid state to utilize their latent heat of fusion to absorb, store and release during such phase conversions. (S.Mondal, 2007)

\[ \text{Fig. 2 Schematic representation of phase Change Materials} \]

2.1.3 Classification of Phase Change Materials
The materials used for the thermal energy storage are classified by the A. Abhat. These materials are classified on the base of Thermal energy storage type and phase change states.

\[ \text{Fig. 3 Classification of energy storage materials (A.Abhat, 1983)} \]
2.1.4 Phase Change Materials for Textiles

Phase change materials have the potential to change the state at constant temperature and store large quantity of energy. One of the most efficient uses of phase change materials can be done in textiles by choosing materials that have large Thermal Energy Storage (TES) and melting point from 15°C to 35°C. The required properties of Phase Change Material (PCM) for the sportswear are mentioned below:

- Large heat of fusion
- Melting point temperature between 15°C to 35°C
- Low toxicity
- Non-flammability
- Ease of availability
- Low price
- For effective heat transfer, large thermal conductivity
- Harmless to environment
- Little temperature difference between the solidification and the melting temperature
- Stability for repetition of solidification and melting point

On the bases of the heat storage capacities, phase change temperature and properties mentioned above the types of materials suitable for textiles especially sportswear are given below with brief description. (S. Mondal, 2007)

**a. Hydrated Inorganic Salts**

Hydrated salts are significant importance to use in Thermal Energy Storage (TES) due to relatively high thermal conductivity (~0.5W/m°C), high volumetric storage density (~350MJ/m³) and moderate costs compared to the linear chain hydrocarbons.

Hydrated inorganic salts with “n” water molecules are very important due to the heat absorbing and heat releasing temperature interval is from 20°C to 40°C. For example, Sodium Sulphate (Na₂SO₄) also known as Glauber’s salts is very attractive due to the thermal storage and melting temperature of 32.4°C. Glauber’s salt hydrated...
(Na₂SO₄·10H₂O) has the convenient temperature of 32.4°C and the melting latent heat of 254kJ/kg. The mode of crystallization process which starts by cooling the TES capsule below 32.4°C in which the phenomenon of crystal growth when crystal nuclei or small crystals already exists in the solution increase its size. The Glauber’s salt containing the 56% water and 44% sodium sulphate is studied for application in textiles. Another important example in the inorganic hydrated salts is Manganese (II) nitrate hexahydrate (Mn(NO₃)₂·6H₂O) which is used because of the general availability, low toxicity and non-flammability. Its density is 1.8x10⁻³ kg/m³. The heat of fusion of Manganese hexa hydrate is 125.9kJ/kg and latent heat per unit volume is 226.6x10⁻³ kJ/m³. Its melting point is 25.8°C and it contains 68% water. (S. Mondal, 2007)

**b. Linear long Chain Hydrocarbons**

Hydrophobic linear hydrocarbons are the byproducts of the oil refinery and have the general formula CₙH₂ₙ₊₂. These materials are inexpensive, having no toxicity and bigger source of raw materials available at different melting temperature ranges according to the no. of carbon items present in the Paraffin. The mostly suitable linear chain hydrocarbons have temperature -5.5°C and 37.5 °C. The phase change temperature can be chosen for the specific applications by selecting the no. of carbon atoms of the hydrocarbons. These are the most important materials used thermal energy storage (TES) and the thermo regulated textiles such as sportswear. The melting temperature of n-Eisocane is 37.5 °C which is about human body temperature. The performance of thermoregulations depends on the heat absorption and heat emission of the hydrocarbons. (S. Mondal, 2007)

It is described in Table 1

**Latent heat adsorption and heat emission of Linear Chain Hydrocarbons**

<table>
<thead>
<tr>
<th>Hydrocarbons</th>
<th>No. of C atoms</th>
<th>Latent heat adsorption (ΔH) in J/g</th>
<th>Latent heat of emission (-ΔH) in J/g</th>
<th>Crystallization Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-Hexadecane</td>
<td>16</td>
<td>235.2</td>
<td>236.6</td>
<td>12.2</td>
</tr>
<tr>
<td>N-Heptadecane</td>
<td>17</td>
<td>176.4</td>
<td>182.6</td>
<td>16.5</td>
</tr>
<tr>
<td>N-Octadecane</td>
<td>18</td>
<td>244.8</td>
<td>246.4</td>
<td>22.0</td>
</tr>
<tr>
<td>N-Nonadecane</td>
<td>19</td>
<td>177.6</td>
<td>182.6</td>
<td>26.4</td>
</tr>
<tr>
<td>N-Eisocane</td>
<td>20</td>
<td>242.0</td>
<td>230.0</td>
<td>30.4</td>
</tr>
</tbody>
</table>
C. Poly Ethylene Glycol and Others

One of the important PCMs for the textile applications is Poly Ethylene Glycol (PEG). The commercially available paraffin is cheap which contains a moderate thermal storage density of (~200kJ/kg) and wide range of melting temperatures. The repeating unit of PEG is ox ethylene (-o-CH₂-CH₂-)ₙ. The melting temperature of the PEG is usually proportional to the molecular weight. (S. Mondal, 2007)

It is described in Table 2

<table>
<thead>
<tr>
<th>Materials</th>
<th>Molecular Weight</th>
<th>Melting Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEG1000</td>
<td>1000</td>
<td>35°C</td>
</tr>
<tr>
<td>PEG1500</td>
<td>1500</td>
<td>50°C</td>
</tr>
<tr>
<td>PEG3400</td>
<td>3400</td>
<td>59°C</td>
</tr>
</tbody>
</table>

2.2 Concept of Thermal Comfort and Heat Balance

The maintenance of even temperature is very important for the human vital functions of whole body. Normal temperature of human body is 37°C, which is changing throughout the day, lower in the morning and it is increasing as the day progressing, high in the evening and then starts decreasing in the night due to the change of environment. The temperature of the body not only changes in the day due to change of weather but also variable in the different parts of the body. For instance the temperature of the inner or core body is higher than the outer parts of the body, the temperature can also rise up to 40°C by the physical activity like sports. The extremities and the surface body also fluctuated by the changes in the ambient air temperature.

For gaining the state of thermal comfort, human produces and dissipates heat energy depending on the ambient temperature. Depending on the nature of activity and sports, human produces and dissipates different amount of heat energy, for example in the state of rest 100 W, in the state of physical effort up to 600 W and in the extreme
Conditions like skiing a human is producing up to 1250 W heat energy. For producing the thermal comfort and to prevent substantial increase in the human body temperature, this heat energy has to be dissipated in the environment. The heat balance of the human body can be ensured if the heat generated is equal to the heat loss. The important factors that can influence the heat balance are the quantity of heat produced by the body due to physical activity, ambient (temperature, pressure of wind, humidity) conditions, the material and construction of the wearer clothes and the individual human body conditions.

Human’s clothing is comfortable if human feels mental satisfaction, physical and physiological satisfaction due to the heat and moisture transfer efficiently from the human body to surrounding environment by the clothing. Therefore in the development of the intelligent fabrics especially that can absorb and release thermal energy and adjusting according to the environment to provide comfort are very important. (Bendkowska, W, 2006)

2.3 PCMs Working In Sportswear and garments

The phase change materials could be encapsulated in the form of liquid before applying to the textile structure. The capsules diameter varies between 10m to 30 Om. The benefits of applying the PCMs in the capsule form are these are resistant to the mechanical actions, heat and chemical resistant. These materials reply to the changing environment in the following manners.

The temperature rises: When the temperature of the body raised due to the higher ambient temperature more than the melting temperature of the PCM, the core material (Phase change material) reacts accordingly and absorbs heat. By absorbing heat chemical bonds are broken and phase change material is started converting from solid to liquid state. During the melting process PCMs absorbs heat energy from the surrounding and stores extra energy.

The temperature falls: when the temperature of the body decreased due to lower ambient temperature less than the crystallization temperature of the PCM, the core material (phase change material) reacts accordingly and releases the previous stored heat. By releasing heat the chemical bond are formed and the core phase change material started converting from liquid to the solid phase. During the crystallization process releases heat to the surrounding and wearer feels thermal comfort.

Microcapsules have the following benefits when applied to the garments,
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- A Cooling effect due to the heat absorption of the Phase change materials
- A heating effect due to the heat emission of the phase change materials
- A thermo regulating effect for the body by heat absorption or heat emission of the PCMs which keeps the temperature nearly at the constant level.
- As an active thermal barrier effect that is resulted by the heat absorbed or released by the PCM which helps in regulation of the heat flux generated in the garment, from human body to the environment and make it suitable according to the thermal needs (ambient temperature, humidity, pressure of air and physical activity performed).

The fabrics treated with micro capsulated PCMs can absorb 4.44 J/g of heat if it contained about 23% of the capsule material melamine formaldehyde during the melting process. The heat absorbed by the capsule material 4.44J/g delayed the increase of temperature on the clothing. In this manner it helped in increasing thermal comfort and reduced heat stress. (Bendkowska, W, 2006)

2.4 Manufacturing of Micro capsulated PCMs

The design and development of PCM have an ability to maintain the thermal energy storage at worse and normal condition. They are incorporated in textile through microencapsulation that are consisted on shell and surrounded core material. They are applied through coating, melt spinning, fiber extrusion method, injection molding, foam manufacturing. PCM have linear hydrocarbon chain known as paraffin waxes, hydrated salt, polyethylene glycol, fatty acid and mixture of organic and non organic compounds. Microcapsule application in textile has an advantage that encapsulation prevents the PCM dispersion in structure, minimizes its evaporation and reduces the reaction of PCM with environment, provides by increasing heat transfer area and constant volume and permits easy application without any side effect. In fiber 5-10% microcapsule are incorporated without effecting softness, drape and strength and no need of processing or washing.

Microcapsules are particles with thickness may be less than one Om and particle size are vary within the range of less than 1Om and more than 300Om depends on the method of encapsulation and diameter vary in between 20 to 40 Om. Microcapsules can be produced by physical and chemical method that are limited to the cost of processing, regulatory affairs and the use of organic solvents that are concerning to environment and health. Physical techniques are employed through spray, centrifugal and fluidized bed process and the chemical are employed through polymerization techniques. The
Cooperation is a miscible process in which the material in dispersed form is added to the polymer solution and then suspended in aqueous phase condition containing surface active agent. Micro capsulation is possible by mixing both water in oil or oil in water method. In this case paraffin/wax in encapsulation has high energy storage about 145 to 240j/g.

In situ polymerization two liquids water and organic solvent are bringing together to react each other and form a solid pre condensate. The situ polymerization has the ability to form a microcapsule with the best ability of diffusion tightness of their walls. In the Micro capsulation study the situ polymerization methods, effect of stirring rate, ph of reaction mixture, content of emulsifying agent, capsule diameter etc. in all these study our purpose is to build a manufacturing that have based on situ polymerization in order to form a microcapsule of PCM that is used in textile application. Second thing is to make it suitable for laboratory scale and industrial scale work to save the energy and time. (Sarier, N, & Onder, E, 2006,)

2.4.1 Experiment

2.4.2 Material selection for the manufacturing microcapsule PCM

Situ-polymerization is the process to produce the required microcapsule by using shell material and some auxiliaries that is mentioned in table below. To improve the strength and high permeability, reaction initiators and anionic polyelectrolyte are required. To improve cross linking, enhancement of shell formation and to prevent bond breaking during the polymerization 1, 3 benezenediol is used that react with formaldehyde.

Table 3

<table>
<thead>
<tr>
<th>Material</th>
<th>Function in polymerization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>Monomer for the shell</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Monomer for the shell</td>
</tr>
<tr>
<td>Sodium salt of dodecyl benzene</td>
<td>Emulsifier</td>
</tr>
<tr>
<td>sulfonic acid</td>
<td>Anionic polyelectrolyte</td>
</tr>
<tr>
<td>Polyethanol</td>
<td></td>
</tr>
<tr>
<td>Triton X100</td>
<td>Non ionic polyelectrolyte</td>
</tr>
<tr>
<td>Ammonium chloride</td>
<td>Reaction initiator</td>
</tr>
<tr>
<td>1,3 benezenediol</td>
<td>Binder</td>
</tr>
</tbody>
</table>

18
Three types of organic materials paraffin which are mostly used in clothing as PCM named as n-hexadecane, n-octadecane and n-Eisocane and they have the important properties of non-toxic, non-corrosive, chemically inert easily available and have no unpleasant odour. These waxes are immiscible in water and have an advantage to serve as an organic phase in interfacial poly condensation. Some other important PCMs of polyethylene glycols (PEGs), PEG600, PEG1000 and hydrated salts Na2CO3.10H2O are also investigated in encapsulation process.

By focusing the core contents, four different combination of PCM, s is selected and characteristics of manufactured microcapsules are compared with control samples containing 100% shell material. These mixtures are prepared to widen the intervals of phase transition temperature enhancing the heat absorbing and releasing capacities of capsule in order to improve stabilization of temperature change. (Sarier, N, & Onder, E, 2006.)

**Table 4**

*Core material and mixture*

<table>
<thead>
<tr>
<th>Type</th>
<th>Content of core</th>
<th>Polymer emulsion on(g)</th>
<th>Percentage of core in the emulsion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mixture</td>
<td>Total mass</td>
<td>Mass to mass ratio</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>n-octadecane</td>
<td>10.3</td>
<td>1.00</td>
</tr>
<tr>
<td>B</td>
<td>n-octadecane/PEG600</td>
<td>38.4</td>
<td>0.13:0.87</td>
</tr>
<tr>
<td>C</td>
<td>n-Eisocane/n-hexadecane</td>
<td>20.8</td>
<td>0.34:0.66</td>
</tr>
<tr>
<td>D</td>
<td>PEG1000/Na2CO3.10H2O/n-hexadecane</td>
<td>51.2</td>
<td>0.50:0.39:0.11</td>
</tr>
</tbody>
</table>
2.4.3 Manufacturing of PCM, s Microcapsule

A double wall reactor is designed and used to achieve laboratory scale encapsulated process by situ- polymerization of urea formaldehyde as shown in fig given below. In this process the main material is capsulated for example n-octadecane s capsulated in urea formaldehyde resin. In the first step aqueous polymer material by mixing 5% of sodium salt of dodecyl benzene sulfonic, 4% PVA, 5% triton x-100 and 5% 1,3 benzenediols. By mass they are mixed in 100 ml distilled water in reaction tank of the reactor at 20°C. 1,3 benzenediol is used to improve the cross-linking in urea formaldehyde resin. Mixture is stirred at 600 rpm for 10 min and then 3.0g of urea, core PCM material and 1-5% by mass NH4Cl is added continuously.

Fig.4. The reactor designed for the manufacture of microcapsules.
By the following mixture containing PCM is formed and this emulsion is stirred at 300 rpm and PH kept at 3.5-4.00 by using buffer solution and then 37% of formaldehyde is added into the dispersion. In the final the reaction is proceed by continuously stirring and pre polymer is synthesized at 50°C for 40 to 60 minute by gradual heating and a constant PH as shown in figure given below. Then the urea formaldehyde capsule is cooled to 25°C and washed continuously and then filtered and vacuum and dried until the formaldehyde is removed till the microcapsule is recovered.

To analyze the characteristics of thermal behavior of PCM,s and their microcapsule, differential scale calorimetric (DSC) analyses is conducted on the Perkin -Elmer / Paris1 type DSC under nitrogen atmosphere. In this analyses test specimens are related and cooled in the temperature range of 0°C TO 55°C at 10°C/min which is mostly used in Microencapsulation tests. To check the thermal behavior of PCM sample is checked against same amount of distilled water in the similar temperature range on Phyfe cobra 3 computers aided data system. In calorimetric tests relatively lower heating and cooling temperatures are preferred.

**Fig5. In situ polymerization of urea-formaldehyde resin.**
Manufactured microcapsule size is also very important for the application according to end use of microcapsule. Particle size distribution is determined by master seizer 2000 instrument which is worked on five sample tests. SEM photos are taken to explain the structural details of microcapsules by type JSM 6335 FNT. One of the challenges in the Microencapsulation is mechanical stability and leakage behavior of microcapsules. It is determined by centrifugal shear force test. In this test microcapsule (0.1g) of samples is put into the test tube in 2 ml of water. Tube is centrifuged at the frequency of 200 rpm at room temperature for 2 to 4 hour. Image of Microcapsule is analyzed by optical microscope for visual comparison. (Sarier, N, & Onder, E, 2006.)

2.5 Incorporation of PCMs Micro capsule in Sportswear

The phase change materials just above and below human’s temperature are suitable for application in sportswear. The thermo regulating properties is possible in the manmade fibers by adding the microcapsules in the solution polymer prior to fibre extrusion. The process of phase change is dynamic as material is changing one phase to another constantly with respect to physical activity of wearer. The most important methods for incorporating microcapsules are mentioned below. (S.Mondal, 2007)

2.5.1 Fiber Technology

For the incorporation of phase change materials into the fiber can be done if the PCM is in the form of micro capsules as explained. PCM microcapsule can be added into the liquid polymer, polymer solution or into the base material so that it can be spun by the conventional methods of spinning for example extrusion of polymer, dry or wet spinning. The micro capsulated can store heat over long time and with the decrease in temperature of the environment, the fiber starts to release heat. (S.Mondal, 2007)

2.5.2 Lamination of PU foam containing Microcapsule PCMs onto a Fabric

Foam based insulation thing containing microcapsule PCM material incorporated in the fabric was developed by Colvin and Bryant 3. In this method the selected material added to the polymer solution and mixed together to ensure complete dispersion and wetting. After that the microcapsules were equally wetted and spaced to each other, the concentration vary from 20% to 60% by weight. Then base foam material was formed. In foaming method basically a hardening agent was added and thermally set through applying a heating method. The microcapsules must be added to the polymeric solution before the hardening process.
After that the foam containing microcapsule were embedded in the base material because the encapsulated material and embedded material were equally spaced so that no free space was created due to the gas. The foam consisted PCMs microcapsule were incorporated in fabric by using neoprene or polyurethane. The application foam pad has a number of benefits because a number of microcapsules were incorporated, a different PCM give a broader range of temperature regulation and microcapsule can be distributed anisotropically between the foam layers. The foam pad microcapsule can be applied in different type of clothing e.g. in shoes, gloves, hats and outerwear. Before application the foam pad is attached with some fabric by the help of glue, fusion or lamination. (Bendkowska, W, 2006)

2.5.3 Incorporation of Micro PCMs to Fibrous Structure by different Process

From many years the PCM was incorporated into fibers to manufacture the fabric for the enhancement of thermal properties. For it a number of experimental tests were performed to achieve the desired requirement. The PCMs are incorporated into fibrous structure with the help of binder (acrylic resin). It can be applied by coating with the help of knife over roll, knife over air, screen printing, gravure printing and dip coating. In the old method the pad mangle method was used to apply the micro PCM on fabric but the spray nozzle method can also be applied.

The coating method was developed by Zuckerman. The coating mixture consisted on micro PCMs, binder, surfactant, dispersing agent, antifoam and a thickener. Surfactant was added to decrease surface tension of microcapsules layer and promoted the wetting antifoam was added to remove trapped air in the mixture. A coating method is prepared by adding dry microcapsule to water to ready the capsule for swelling and it is completed in 6 to 24 hours. Mostly the PH of mixture is adjusted to 8.5 or more than this to enhance swelling of microcapsule. Mostly adjust the PH of mixture close to the PH of microcapsule. Mostly used binder in the mixture that is used for the fixation of microcapsule has some drawbacks such as drape, air permeability, breathability, thermal resistance, softness and tensile strength can be affected as the percentage of binder increases. Pushaw 9 found that it is difficult to maintain the durability, permeability, elasticity and softness when the coating was loaded with high content of micro PCM. The mean diameter of microcapsule was varying from 1 to 1.5 mm and the average varies from 3 to 5 mm and they have the spherical shape. The latent heat of microcapsule was higher due to their greater volume and the coated have round about 14 J/g i.e. enough for 30 laundering. The water repellency of coated fabric were same as to without PCM fabric and the only the water resistance is decreased. (S.Mondal, 2007)
2.6 Testing of Textile Clothing Containing PCMs

The traditionally thermal insulation method rely on the air trapped system was used for the performance of PCM material that was an old system. In this test method the conduction of heat was measured through fiber or air voids. The CLO or TOG test methods were designed to measure this effect. The fabrics contain PCM materials form a dynamic system that responds to human body conditions and external environmental conditions. So, the traditionally old air trapped systems do not calculate properly the benefits of PCM. (S. Mondal, 2007)

After all the best types of testing PCM material that was close to the human psychological nature was approved in 2004 by American society of testing and materials but these type of testing were very time consuming, costly and can never be used for routine quality control testing. By the research of numbers of years on textile containing PCM the first test method (ASTM D7024) is established by Outlast technologies, incl, and prof. Dr. Douglas Hittle, director solar energy application at Colorado state university. (Intelligent textile book, 2006)

Phase change material with temperature regulating and enhancement of latent energy has provided a new dimension in the body comfort against the changing environment (surrounding). The existing testing procedure covers the testing of insulation in traditional fabric but enable to calculate the store energy in these new innovative materials. For thermal transmittance of the textile materials the new test method called ASTM D1518 was developed that calculate the R-value or CLO value that is used for garment industry in steady state. This new test method used to measure the temperature changes, their differential and calculate the temperature changes in a dynamic environment. This test method worked on the principle of effects created by temperature changes and the fabric nature of absorb, store and release energy. This test provided the evidence of measuring of PCM store energy is different from the traditional method. (Intelligent textile book, 2006)

Another test method used to measure the heat capacity or enthalpy of encapsulated PCM fabric named as differential scanning calorimetric method (DSC). This was very popular method initially used for the calculation of melting and crystallization point and the ranges of heat absorption and heat releasing ranges of PCM materials. Another test method named as thermal-gravimetric analysis (TGA) method that was basically used for the calculation of thermal strength of PCM material. This test was very important for thermal calculation because the fiber containing micro capsulated PCM is subjected to convert it into yarn and fabric that consume heat. (Intelligent textile book, 2006)
2.7 PCM Finishes:

Microencapsulation is a process in which small particles of liquid or solid are covered by some coating material with some useful advantages. Microcapsule in its simple form look like a sphere round shell around a small droplet of liquid and the material inside the shell considered as the main core material. The membrane of the microcapsule consisted on few micrometers or millimetres and the microcapsule have the little bit resemblance to the sphere. The microcapsule core may be the crystal of small droplet or it is suspension of small droplet of microcapsule and the microcapsule may be consisted on multiple walls. (Intelligent textile book, 2007)

Microencapsulation is a novel concept to get a functional finishes on textiles. The capsule has no affinity with textiles without any binder to get the durable finish and the fixation is done at 150 – 160c® for 2 to 3 minute to make the effected cross linking of binder and tightly fixation of capsule on the fabric. At the curing stage there is a risk to aroma inside the capsule due to quick evaporation that breaks the capsule. "The loss from the capsule can seriously reduce the amount of aroma on the fabric and decrease the amount of durability”.

A roughly after 20-25 normal washes aroma capsule finish can lost and to avoid this UV resin finish can be applied at low temperature and give the time in seconds. During the curing of that finish the loss of aroma is limited that is ensuring the durability of the finish. A thermal curing process is used for curing aroma capsule finished cotton fabric that can bear 25 washes only. To avoid this UV resin is used that can be cured at low temperature and the fabric selected with aroma capsule and UV resin can be cured at optimal conditions that can be allowed to 50 washes. (Intelligent textile book, 2006)

Other applications like insects repellent, dyes, vitamins, antimicrobials etc. can be applied that could be benefited from micro encapsulation technologies for any area of industry. The work fragrance finishes is continued from many years for fabric containing that is done in wash and tumble drying to achieve aroma of fabric. But is not a permanent it is just a temporary effect that is lost after first or second wash and there is no quality of technology to impart the fragrance finishes. It is mostly done for children clothes also work wear or at home application clothes. In future the perfumes like application will be done to make more attractive.
Cellessence international of Hatch end, middle sex are working on micro capsulation fragrant smelling from many years, in the earlier years they are working on other things like application of drawer line, gift wrapping, greeting cards, handkerchiefs, stationary etc and they newly have started work on textile by using the technology of microencapsulation fragrant smell in synthetic capsule. The size of capsule range from 1 to 20 um and it show that how much size is minimum the fragrance is also greater. Initially the scratch and sniff technique of microcapsule application was applied by screen printing but now a day’s web printing technique is applied. In the 1999 Cellessence formed an alliance with some book stone chemicals that allow using different fragrant chemicals, vitamins, moisturiser and even different insect repellent to fabric. The applied things depend on weight and the wash cycle that are up to 30 cycles without losing fragrance. The aqueous dispersion of encapsulation is applied by pad method, exhaustion method or hydro extraction method to fabric and the performance and handle is further improved by using some binder and softener. (Intelligent textile book, 2006)

2.8 Quality Issues of the Phase Change Materials and Clothing

2.8.1 Thermal Conductivity of Phase Change Materials

The most commonly used phase change materials are paraffin because these materials have the advantage to store a large amount of latent heat over a small temperature variation. But the phase change materials containing the paraffin have some disadvantages such as the low heat conductivity of these materials. The heat conductivity of some paraffin is too low to provide suitable heat exchange rate between the substrate and the phase change materials for thermal comfort of the wearer. To efficiently utilize the stored heat of PCM, there is need to use some materials called “Thermal Conductivity Enhancer” to increase heat exchange rate.

The thermal conductivity of the phase change materials can be enhanced by using the metal fillers, carbon magnifier/fiber fillers etc. The carbon nanofiber is mostly used as the thermal conductivity enhancer due to corrosive resistant, chemical resistant and its density is less than 2260kg/m$^3$ which is lower than other metal additives. So, for the application of the phase change materials in textiles carbon magnifier/fibre is efficient thermal conductivity enhancer. The carbon magnifier can be introduced by shear mixing and melting techniques into PCM. By using the mass ratio of carbon magnifier the cooling rate during solidification process of new Nan composite can significantly increased. (Intelligent textile book, 2006)
The effectiveness of the Thermal Conductivity Enhancer (TCE) was investigated by the Nayak et al in PCM. According to Nayak et al by adding Aluminium matrix (metal filler) into the Eicosane increased not only the thermal conductivity as well as melting rate. The efficiency and effectiveness of the TCE can also be improved by distributing the material in the form of thinner especially rod type fins were better than plate type thinner fins which maintained better uniformity of temperature within PCM. (Intelligent textile book, 2006)

2.8.2 The leakage of Phase Change Material

The Phase Change Materials containing the paraffin have the disadvantage of the leakage of core material (Paraffin) from the capsule when subjected to the mechanical stress and hot climate. To cop up with this problem the paraffin and expanded graphite (EG) composite PCMs can be manufactured by inserting or impregnating the liquid paraffin into the porous Ethylene Glycol (EG). The critical aspect in adding EG is due to the decrease in the density of the PCM, the Latent Heat Thermal Energy Storage (LHTES) system is affected. But this effect can be minimized by adding 10% (E.G). This critical aspect indicates that the high relation between the mass of EG and the thermal conductivity in the PCM. (S.Mondal, 2007)

2.8.3 Fire Hazard Treatment

Fire hazard is also a quality problem along with the thermal conductivity and leakage of the incorporated phase change materials containing the phase change materials. To eliminate this problems, different techniques is being adopted but the two commonly treatments used are improvement in the flame retardant treatment and the application of the PCM in the sandwich construction between the two fabrics.

Cai et al. prepared and examined the stable PCM containing the High Density Polyethylene (HDPE)/Paraffin Hybrid with different combinations of the flame retardant systems by using twin extruder techniques. In this combination it is observed that as compared to stable PCMs, the weight of char residues in flame retardant form stable PCMs is found to be higher but it is observed from DSC (differential Scanning Calorimeter) that it had no effect on the latent heat. So, it is cleared that flame retardants has no affect on the thermal energy storage. In another combination, PCM based on the High Density poly ethylene, paraffin, organophilic montmorillonite (OMT) and Intumescent Flame Retardant (IFR), hybrids are examined. Addition of the OMT and the IFR reduces the heat release rate (HRR) contributing in the improvement of the flammability performance and no effect on latent heat observed by DSC. (S.Mondal, 2007)
2.8.4 Particle Size Distribution

The capsule size generally varies between 10m to 5000m in diameter depending upon the material of capsulation and the core materials. (See Table 3) But for type B and C, the capsule size was obtained <2000m for about 50% of PCM and also in considerable amount less than 500m. These results showed that the method of capsulation used is suitable for producing the capsulated phase change materials with different ranges for sportswear.

The other aspect which is also very important is the particle size distribution is differing from each other due to the type of core materials. Microcapsules of type A which encircles n-octadecane molecules are larger than the Type C containing the n-hexadecane those covered by the polymer shell. Thus capsule size obtained tends to be smaller.

Another important factor that is affecting the size of the particle was the stirring during the interfacial poly condensation technique. The lower rate of stirring may be affected especially after adding the second monomer. (Intelligent textile book, 2006)

Table 5. *Particle sizes in micrometer correspond to the particular percentages of the size distributions*

<table>
<thead>
<tr>
<th>Capsule Type</th>
<th>capsule Size in Om</th>
<th>Mean</th>
<th>% of P size≤50</th>
<th>% of P size51-100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
<td>50%</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>44</td>
<td>196</td>
<td>560</td>
<td>269</td>
</tr>
<tr>
<td>A</td>
<td>47</td>
<td>411</td>
<td>1202</td>
<td>527</td>
</tr>
<tr>
<td>B</td>
<td>33</td>
<td>201</td>
<td>704</td>
<td>296</td>
</tr>
<tr>
<td>C</td>
<td>07</td>
<td>41</td>
<td>185</td>
<td>69</td>
</tr>
</tbody>
</table>
2.8.5 The Performance of Micro capsulated PCMs

From the skin the heat loss to the environment is occurred by conviction, radiation and evaporation with the help of the latent and sensible heat of perspiration, but the clothing provides the resistant to heat flow. The one of the prime objective of the clothing is to create a stable microclimate for the thermal protection close to the skin to provide for supporting the body’s thermo regulating system, even the physical activities and the external environment changes in the broader range. If the product liked encapsulated phase change material is of significant importance that can provide enhanced thermal capacity in addition to the existing passive insulation characteristics of structure to increase the comfort state of body.

Active wear's thermal performance can be improved textile clothing with thermo regulating properties. In textile clothing the most important source of thermo regulating properties are phase change materials. Suitable thermo regulating effects can be achieved only when specific design principles are applied on the garments in the product design and development stage. It is very important for example the quantity of phase change material applied on the active wear according to the duration of the garment used and the level of activity. Another factor that can influence the thermo regulated effect is good design of construction for garment.

For the best functionality and performance, the fabric system should be bi functional for both the exothermic and endothermic environment. (H.Matilla, 2006)

2.9 Applications OF PCM

There are many phases involved in fiber evolution. It starts from conventional fibers and the second phase of this evolution was high functional fibers and at the end high performance fibers are formed. All these fiber development stages are formed because of need and relevant application. Polyester is a fiber which is most commonly used for active and sportswear. Other fibers those suits for active wears are polypropylene and polyamide.

There are several applications of phase change material PCM, including textile apparels, protective garments, medical and insulations. The brief description of the applications of PCM in textiles is defined follows.
2.9.1 Space:
The PCM technology was developed for astronauts first time. This material is used in astronaut’s suits and gloves to protect them from the bitter cold temperature in space to make them comfortable. The temperature can go to -270 degree Celsius.

![Picture 01](image)

2.9.2 Sportswear
Now a day Phase Change Material is also used in consumer products as well as the original application of space suits. The 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 use 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. (S.Mondal, 2007)
2.9.3 Household Accessories:
Micro capsulation, which is embedded in pillow, mattress and quilts, controls the bed temperature. It acts when the body temperature is 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. (S. Mondal, 2007)

2.9.4 Medical Applications:
The potentially application of PCM micro capsulation are in surgical apparels, patient bedding, bandages and the products related to regulate patient temperature in intensive care units. In medical and hygiene applications, where both liquid transportation and anti bacterial properties are required, the PEG treated fabrics are useful. For example surgical gloves and nappies etc. in case of Heat/Cool therapy and burning cases thermo regulating textile is useful. (S. Mondal, 2007)

2.9.5 Automobiles:
PCM can be used in automobile textiles such as seat covers. Because paraffin properties for heat storage, corrosiveness, lack of toxicity, it could be used in automobile interiors. PCM treated fabric in headliners and seats provide the superior thermal control.
2.9.6 Accessories:
The phase change material reacts directly exterior of the garment and body temperature, so it also used in footwear, especially race car drivers, mountaineering boots and ski boots. PCM (paraffin) contained micro capsulation are linked to a specific temperature range depending on end use (36 degree Celsius for a motor cycle helmet and 26 degree Celsius for gloves).

This thermo capsulation can absorb, store, distribute and release heat at wearer head, body, hands and feet. In the case of ski boots, the material absorbs heat when feet generate the excessive heat and send back to the spot when feet get cooled.

Fishing waders and firefighter suits are some other examples of application of PCM in textile.(S.Mondal, 2007)

2.10 Modifications
Now a day’s Phase Change Materials are used in consumer products were originally developed for astronaut suits and gloves to protect them from the extreme temperature
Fluctuation in space. There are many modifications required in this newly innovative material. The integration of PCM requires development of new standards and testing methods rather than based on conventional methods.

The development of materials requires, such as their mechanical properties, durability and functionality in various conditions. The main problem of manufacturing of PCM textiles is the method of application. Now we are using only one method is encapsulation of PCM in polymeric shell, but this also increase the weight of active wear. Stability of encapsulation, yield of encapsulation and integration of encapsulation into fabric structure are also the key technological issues those should be considered. Awareness of textile community for the PCM micro capsulation is also a big problem for incorporated textiles in repeated uses. (S.Mondal, 2007)

Chapter 3

3.1 Findings and Suggestions

By considering the conditions in the process that are employed in the manufacturing of pleurae-formaldehyde shells encapsulating paraffin waxes that have low stirring rates, low heating requirement, short polymerization duration, ordinary atmosphere and atmospheric pressure, etc.,

The thermal properties of fabrics including micro encapsulated PCM can be designed to be dynamic and actively responsive for some special end-use fields. Against these general criticisms that their actions are limited by phase changing, a continuous phase change transition ambience in the clothing with a relevant thermal insulation capability can be held by some arrangements. In this process the outer fabric layer can be acted as a collector of the environmental heat and the inner layer can be performed as functional in an interval near skin temperature for the cold weather conditions.

To enhance the thermal performance of fabrics or to increase their phase transition temperature intervals, is a much better way to use a combination of microcapsules containing different types of PCMs rather than those including a mixture of them. The microcapsules containing PCMs further increased their heat performances.

3.2 Discussions

In textile processing, especially in the nonwovens business, microencapsulated PCM are on the market already. Microencapsulation of liquids and solids is an innovative micro packaging technology which is opening up new marketing opportunities to
Increase the performance of apparel markets for creating smart thermo-regulated textiles. To avoid the problem of oil leakage and to protect other significant destruction of PCM fabric capsules is treated after the centrifugal shear force tests performed to check the mechanical behavior of fabrics. Therefore, the manufacturing of thermo-capsules is analyzed for the application in other fields. The application of PCM fabrics is very wide from military use to construction industry and entertainments like sports. The main application of PCM fabrics are mainly in military, health care and performance sportswear. Surely, PCM incorporated textile will take a major role in the future smart textile segments.

In the modern competitive market situation in the world, the demand of the customer is to get comfort in cloths, which respect to be worn in different situations from daily wear to functional wear. Phase change materials are one of the main source in synthetic fibers that are increasing value with respect to comfort to wearer.

### 3.3 Conclusions

During the study of this project that PCM based textiles has the bright future. At this stage we cannot describe it completely because this technology is in developing stage. But here we can explain its function in the form of SWAT analysis.

<table>
<thead>
<tr>
<th>Strength</th>
<th>Weakness</th>
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<tbody>
<tr>
<td>3 PCMs can store and release high amount of energy at small temperature difference</td>
<td>3 Unavailability of testing standards for clothing containing microcapsulated PCMs</td>
</tr>
<tr>
<td>3 Low price Materials</td>
<td>3 Difficult to incorporate PCMs in clothing structure</td>
</tr>
<tr>
<td>3 Environment friendly</td>
<td>3 Polymeric shell puts dead weight to clothing</td>
</tr>
<tr>
<td>3 Ease of availability</td>
<td></td>
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<tr>
<td>3 Low toxicity OF PCMs</td>
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Ultra Smart Textiles in Sports Wear and Garments

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Threats</th>
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<tr>
<td>3  These materials can be applied in the technical textiles</td>
<td>3  Durability of PCM incorporated textile in repeated uses</td>
</tr>
<tr>
<td>3  The market demand for PCMs containing textiles is increasing due increase in outdoor sports and safety equipments</td>
<td>3  Thermal conductivity of phase change materials that can transfer heat to and from the environment</td>
</tr>
<tr>
<td>3  New incorporating techniques increasing PCMs application like injection moulding and foaming</td>
<td>3  Fire hazard treatment</td>
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<tr>
<td></td>
<td>3  The functionality of PCMs containing microcapsules.</td>
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3.4 References


B. Pause, Textiles with improved thermal capabilities through the application of phase change material (PCM) microcapsules, Melliland Textilberichte 81 (9) (2000) 753–754