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Enhancing Thermal Management in Protective Textiles Using Hydrated Salt as Phase Change Materials

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Abstract

The thermal properties of textiles are essential for ensuring the comfort of both fabric and clothing systems. Phase change materials (PCMs), which contain latent heat, play a significant role in this area. As ambient temperature fluctuates, PCMs absorb heat, melt or release heat, and solidify. Throughout these melting and crystallizing processes, the temperature of the PCM remains constant. Integrating suitable PCMs into garments helps maintain a stable temperature within the micro-environment between the garment and the wearer. The effectiveness depends on the quantity of PCMs used. This study synthesised and evaluated a novel type of nano-capsule containing PCM Glauber's salt. Advanced techniques such as Differential Scanning Calorimetry (DSC), Scanning Electron Microscopy (SEM), and Fourier-Transform Infrared Spectroscopy (FTIR) were employed to analyze the developed nano-capsules. Additionally, a finite element model was created to enhance the understanding of the thermal mechanisms in textiles incorporating PCMs. This comprehensive analysis aims to promote the application of PCMs in protective textiles, contributing to developing next-generation materials that provide thermal regulation and protection for the wearer.

Keywords: Protective Textiles; Temperature Management; Phase Change Materials; Latent Heat; Nano Encapsulation; Finite Element Simulation

1 Introduction

The development of advanced materials has brought significant improvements in various fields, including enhancing protective textiles. One notable innovation is the integration of Phase Change Materials (PCMs) into textile fibres to improve thermal management. Protective textiles are crucial in various applications, such as firefighting, military operations, and extreme sports, where efficient thermal regulation is essential for safety, comfort, and performance [1-5].

Traditional textiles often fail to provide adequate thermal control, particularly in extreme temperature fluctuations. This inadequacy can lead to discomfort and, in severe cases, endanger the

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wearer's health and safety [6]. PCMs offer an innovative solution by utilizing their capacity to absorb, store, and release latent heat during phase transitions, thereby ensuring a stable temperature [7]. When embedded into textiles, PCMs can dynamically react to temperature fluctuations, significantly improving the thermal performance of the fabric [8]. Heat and moisture transfer behaviour in clothing has long been recognized as vital for human survival. PCMs, organic or inorganic compounds, store significant amounts of heat energy as latent heat, which is absorbed or released when the material transitions between solid and liquid states. Microencapsulated PCMs (MicroPCMs) can be integrated into synthetic filaments or applied to fabrics using various methods. Throughout the phase change process, the PCM maintains a nearly constant temperature. Textiles incorporating these smart materials can offer passive insulation, shielding the wearer from extreme environmental conditions.

Integrating PCMs into textiles enables fabrics to dynamically respond to environmental temperature changes, significantly improving thermal management properties. Various techniques have been explored for textiles' active and passive personal thermal management. Zhao et al. [9] developed a textile thermal management device with multi-functions. It can be used to warm the wear while effectively reducing energy consumption. Additionally, Yoo et al. examined practical considerations such as durability, washability, and the real-world effectiveness of PCM-enhanced textiles [10, 11].

Presently, commercially available encapsulated PCMs are primarily paraffin-based and exist in micro-scale capsules with sizes up to 40 microns, featuring a phase change temperature of 28 $^\circ$ C. The particle size poses issues during the extrusion process, including potential blockages in spinneret holes. To address these extrusion-related challenges, nano-encapsulated PCMs (NPCMs) are required. Sodium sulfate decahydrate (Glauber's salt) offers a phase change temperature close to the human comfort range. It has a higher latent heat capacity than paraffin and is significantly more cost-effective. This research paper reports the encapsulation techniques and processes used to develop NPCM Glauber's salt and the properties of the smart composite nanoscaled capsules. Finite analysis has been used for thermal analysis by many [12, 13]. FE analysis will also be carried out to better understand the thermal regulation behaviour of textiles incorporated with PCM.

2 Materials and Methods

A technique has been developed for encapsulating Glauber's salt $Na_2SO_4.10H_2O$ with a PMMA shell. Non-volatile solvents, toluene and dichloromethane, were chosen for emulsion preparation due to the hydrophilic nature and low melting point of the hydrated salt. Tween® served as the emulsifier, while polyvinyl alcohol was the emulsion stabilizer. Dibenzoyl peroxide was utilized as the initiator. All chemicals were sourced from Alfa Aesar®. The solvent evaporation method encapsulated Glauber's salt, following the procedure illustrated in Fig. 1.

To prepare the Glauber's salt emulsion, 20 grams of Glauber's salt were dissolved in 80 millilitres of toluene, an organic solvent, along with an emulsifying agent. An ultrasonic homogenizer was used for 5 minutes at 30 °C to ensure a high-quality emulsion. Subsequently, 5 milligrams of polyvinyl alcohol (PVA) were added to stabilize the emulsion. The prepolymer solution was created by mixing 12 grams of MMA and 2 grams of EA in 50 millilitres of dichloromethane, stirring at room temperature until a clear solution was achieved. Half of the emulsion was transferred into a three-neck flask, and the prepolymer solution was slowly added. An initiator and stabiliser