Smart Fabrics: Microencapsulation of Phase Change Materials and Their Application for Thermo-Regulated Textiles

Yeong-Hui Seo Literature Seminar October 12, 2017

A core body temperature of 36.5 °C is required for humans, and a rise or fall of 1.5 °C can be fatal.[1] In order to keep a constant body temperature in the extreme temperature fluctuations in space, the US National Aeronautics and Space Administration used liquid cooling garments for the Apollo program in the 1970s.[1] They were designed to keep an astronaut's body temperature within the normal range by circulating cool water through the tubes. This water-circulating garment would be hard to use in normal life because it requires carrying a heavy water reservoir, motor, and battery.

Phase change materials (PCMs) are a good, potential option for realizing thermo-regulated textiles in everyday life. PCMs, which can convert from solid to liquid or vice versa, are the most frequently used latent heat-storage material, and are suitable for the manufacturing of thermo-regulated textiles and clothing. During the melting phase change, the PCMs absorb latent heat from the surrounding area. In a same manner, when PCMs are subjected to a cold environment, where the temperature is below their crystallization point, it will interrupt the cooling effect of the fabric, and the temperature of the fabric will stay constant at the crystallization point.[1] Let's suppose that you are wearing PCMs-incorporated thermo-regulated clothing. It will increase your endurance and make you more comfortable by staying warm in a cold environment, and by staying cool in a hot one. It does not require you to carry a heavy water reservoir, motor, or battery.

Linear hydrocarbons are latent heat-storage materials which are non-toxic, and have extensive sources for their raw materials. Among the several linear hydrocarbons, not all can be used for thermo-regulated textiles. Because PCMs should change phase in a temperature range near human-skin temperature (around 33.4 °C),[1] n-octadecane and n-eicosane are good candidates as PCMs due to their appropriate melting temperature.[1] The melting and crystallization temperatures of n-octadecane and n-eicosane are 28.2, 25.4 and 36.6, 30.6 °C, respectively.

To apply PCMs to textile structures, they are encapsulated in micrometer-size spheres. In order to contain them in the liquid phase, encapsulation is conducted using interfacial polymerization.[4-9] In addition, microencapsulation is an effective way of preventing possible interaction with the surroundings. In interfacial polymerization, an oil solution contains monomers and PCMs. An oil-in-water microemulsion is formed by dropping the oil solution into the aqueous solution with an emulsifier. During this stage, the emulsifier micelles trimly cover the surfaces of the monomer/PCM mixture oil droplets with hydrophobic chains oriented inward toward the oil droplets and hydrophilic groups oriented outward away from the oil droplets. Subsequently, another aqueous monomer solution is added into the emulsion, which reacts with the first monomer, forming shells. The shell materials, melamine formaldehyde,[6-7] an acrylic-based polymer,[3-4] and polyurea[5,8] are synthesized using linear hydrocarbons as the core material. The preparation of microencapsulated PCMs (MPCMs) is optimized with different core/monomer ratios[9] and different amounts of emulsifier.[8] The prepared MPCMs are incorporated into core fibers by a wetspinning process.[4] A sheath layer is coated on the composite fiber by a solvent evaporation method to protect the exposed MPCMs and to enhance the composite fiber strength as well. Sun et al.[7] used another method for the incorporation of MPCMs and nanoencapsulated PCMs (NPCMs) into cotton fabric. They used a pad-dry-cure process in the presence of a binder. For the MPCMs, after five washings, the microcapsules were still present but not in large numbers. For the NPCMs, after five washings, the nanocapsules were more firmly attached, showing better resistance to washing. The smaller the size of the capsules, the more firmly they bind to the fabric.

The average latent heat of melting (ΔH_m) and crystallization (ΔH_c) for n-octadecane and n-eicosane are 245.6 J/g and 236 J/g, respectively.[2] The latent heat of the PCMs is decreased when they are microencapsulated because the portion of PCMs is decreased due to the shell materials. In addition, there may be residual solvent or emulsifier. For microcapsules containing n-octadecane, the avg. measured latent heat of melting and crystallization have been reported to be around 114-188.4 J/g, corresponding to PCMs contents calculated at about 70wt.%.[3-5] The latent heat is further decreased when MPCMs are incorporated into the fabrics or fibers and when the MPCMs-incorporated fabrics are washed.[6-7] Shin et al.[6] synthesized microcapsules containing n-eicosane as the core material. They determined that the latent heat of the MPCMs was 134.3 J/g. The maximum latent heat of MPCMs-incorporated polyester-knit fabrics was determined as 4.44 J/g, and it was reduced to 1.7 J/g after five washings. Sun et al.[7] used commercial MPCMs containing paraffin wax as the core material. Their latent heat was 185 J/g. The latent heat of MPCMs-incorporated cotton was determined as 14.6 J/g, and it was reduced to 2.4 J/g after five washings. Sun et al.[7] synthesized NPCMs using n-octadecane and n-eicosane in a 2 to 1 ratio by weight as the core materials. Their latent heat was 144 J/g. The latent heat of NPCMs-incorporated cotton was determined to be 12.3 J/g, and it was reduced to 4.64 J/g after five washings. There is no numerically known value about the exact amount of MPCMs to be applied to textiles efficiently because there are many factors to be considered and it is too arguable. However, we can imagine a person wearing microencapsulated n-octadecane-incorporated clothing in a closed system. The temperature of this person’s skin is 38 °C, so, the person will feel comfortable at 37 °C. The total heat required to reduce 1 °C from this person’s skin temperature is 237,370 J. It is assumed that this person is a healthy man whose height is 5’ 10’’ and weight is 70 Kg, based on the BMI index. 1.4 Kg of microencapsulated n-octadecane is required when we assume that 1) the avg. latent heat of MPCMs is 166 J/g and 2) their latent heat is constant after incorporation into the fabric. In addition, we assume a 100% of thermal conductivity of PCMs, no air permeability, and no moisture vapor transmission in the fabric. A speed of metabolism, time needed for thermal equilibrium, affect by sweating, and affect by opened spaces in clothes on the skin temperature were ignored.

In the future, the latent heat of MPCMs should be enhanced to reduce the amount required for the actual application. The nanoencapsulation approach is going on for enhancing thermal performance. Mechanical properties such as the tensile strength and elasticity of the final fabric should be enhanced as well for the actual application. There is not yet a standard to characterize the thermal performance of PCMs-incorporated fabrics. More specific methods need to be established. A recent paper published this year (2017) described the microencapsulation of n-octadecane with different reaction conditions.[3] It did not examine the incorporation of the microcapsules in fabric, but the results were published in a journal whose impact factor is around

3. If we could connect PCMs to the right application data, it would have a big impact. We can collaborate with scientists from medical fields who study metabolisms for exact calculations and right access to the application.

References

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