Novel Temperature Regulating Fibers and Garments

Background

The regulation of the body temperature is controlled by the release of heat by blood vessel dilatation or constriction, muscle (shivering) and sweat gland activity. Thermal comfort is dependent upon both environmental and individual factors and is influenced by the core and skin temperatures of the body. There are four essential conditions for a person to be in state of thermal comfort; 1) the body is in heat balance; 2) sweat rate is within comfort limits; 3) mean skin temperature is within comfort limits (33-35°C); 4) local discomfort is absent. The thermoneutral zone for naked resting subjects has been defined to lie between 28-30°C (ambient temperature). In this comfort zone the human body is unaware of warmth or coolness. Outside this range the body feels discomfort. This means that the balance between the rates of heat loss and heat generated must be maintained. This is usually done by putting on or taking off clothes. However, in many situations it would be a significant advantage if the cloths could play an active role in maintaining the body within the thermal comfort zone without taking them off or on that frequently. Especially during short term changing conditions this would be of particular relevance. For instance, moving between air conditioned locations in warm climates or going in and out from stores in cold climates. Also during short term intermittent physical activity it would be advantageous if the cloths could buffer some of the energy released by the body. For instance, after a short run to the bus stop or departure gate, a cooling effect preventing start of sweating would be of interest.

The objective of the recently finalized EU-funded research project NoTeReFiGa (http://extra.ivf.se/noterefiga) was to develop novel temperature regulating fibers and innovative textile products for thermal management and improved comfort. The temperature regulating effect is achieved by novel methods of incorporating large amounts of phase changing materials (PCM) in textile fibers. When the body temperature increases, the PCM melts and absorbs the heat from the body in the form of latent heat (cooling effect). When the temperature drops, the PCM crystallizes and the stored heat is released again (warming effect). It is assumed that clothes with built-in thermo-regulating properties will provide maintained thermal comfort in difficult thermal environments and physical activity situations.

Technologies for incorporating PCMs in textile fibers

PCMs can be integrated into textile fibers both by means of melt spun bi-component fibers with a sheath/core structure and by using solution spun cellulosic fibers with a dispersed PCM phase, see Figure 1. In this way PCM is permanently trapped inside the fibers. Both types of fibers have been successfully developed within the NoTeReFiGa project.

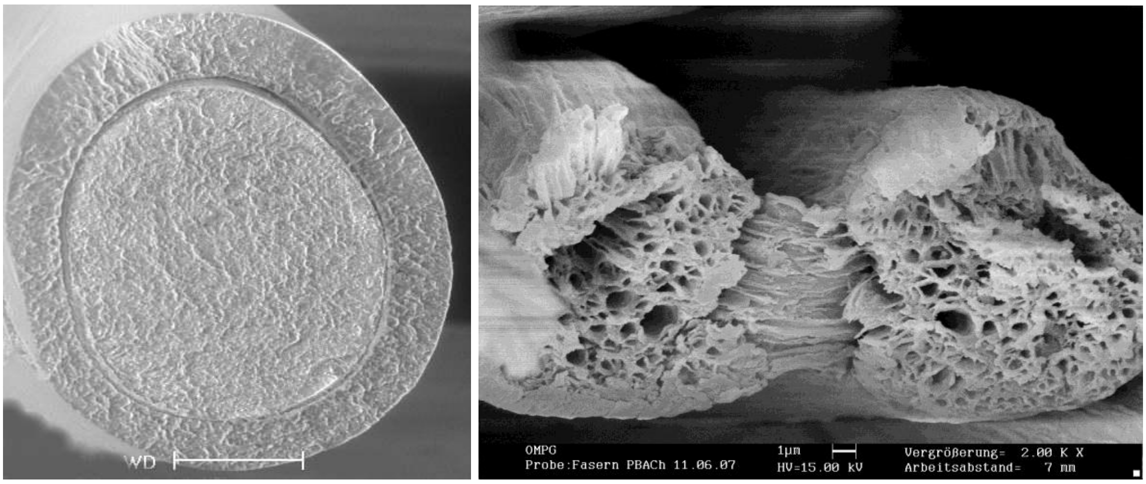

Figure 1. Cross section of a melt spun PCM fiber with a core/sheath structure (left) and a wet spun Lyocell fiber with directly incorporated PCM (right).

Melt spun bi-component fibers with PCM

Optimized PCM/polymer alloys based on paraffin wax and polyolefin viscosity modifiers with regard to thermal efficiency, melt viscosity and cost in order to produce melt spun bi-component fibers with a latent heat greater than 60 J/g in the temperature range 27-36 °C and with sufficient strength for use in garments and other products (tenacity greater than about 20 cN/tex) has been demonstrated in industrial scale production. An example of PA6 fibers with PCM in core is shown in Figure 2.

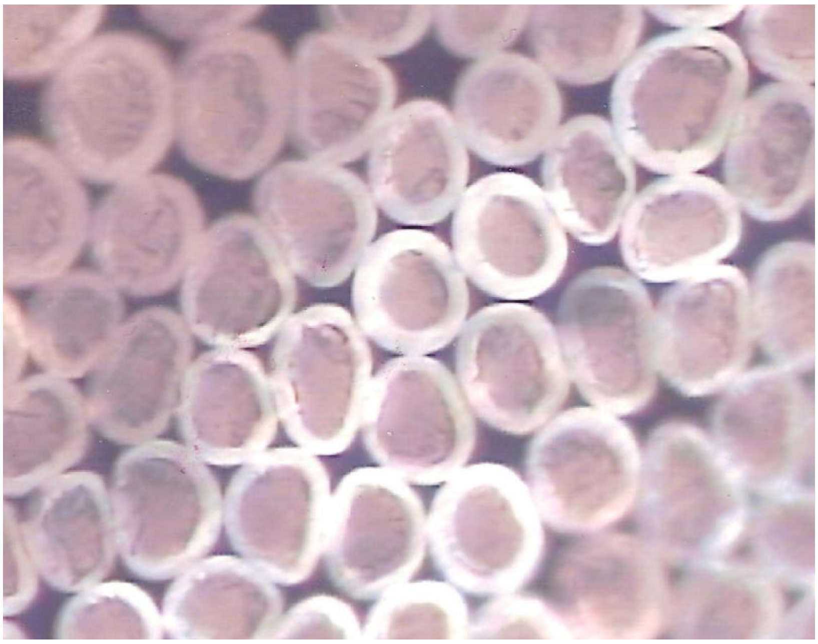

Figure 2. Melt spun PA6 fibers with PCM/polymer alloy in core produced on commercial scale spinning equipment.

An industrially feasible and efficient processing concept to produce PCM/polymer alloy with 70% PCM and more in the form of free flowing particles was also demonstrated. The PCM/polymer alloys are possible to use with standard melt spinning grades of PLA, PET and PA and produce fibers fulfilling the requirements set by the final applications (texturing, dying, finishing, wash ability, health and safety aspects, cost etc.). PP was found not suitable for fiber production due to migration of PCM. In order to produce fibers with PCM/polymer alloy on standard industrial extrusion equipment it was found necessary to apply certain proprietary precautions. Suitable bio-based PCMs were identified and used in the project. However, a bio-based viscosity modifier for the PCM was not found. This means that about 10-15 % of the fiber weight will be from non-renewable sources (crude oil) in case of a PLA sheath polymer (bio-based sheath polymer).

Lyocell type fibers with PCM
Wet spun cellulosic fibers containing PCM where obtained using tertiary amine oxide N-methyl-morpholin-N-oxid to dissolve the cellulose. Ensuing from the technology incorporating microencapsulated PCM, the goal was to integrate free PCMs in the cellulosic fiber matrix to achieve higher capacities of heat and finer titers.

Hydrocarbon based waxes such as linear alkyl ethers can be used acting as PCM in the fibers. The main problem is the thermodynamic incompatibility between the phases of hydrophobic PCM and hydrophilic cellulose. Silicic acids can be used to disperse the PCM homogenously and isotropic on the one hand and layered silicates e. g. nanoclays to enclose the PCM and fix them permanently in the cellulosic fiber matrix. The function of layered silicates is to mediate between the hydrophilic cellulose and the hydrophobic PCM because they are hydrophilic at the one side and hydrophobic on the other side. Additionally, a copolymer is used to interact between the complexes of silicic acids and PCM enclosed between the layers of the nanoclays and fiber matrix. Whereas the amount of PCM in the fibers regulates the capacity of heat, the number of carbon atoms in the chain of the hydrocarbons regulates the transition temperature of the PCM to adapt the fibers thermo physiological properties to the requirements of use in a wide range.

It was possible to produce very fine textile fibers in a range between 1.7 to 2.5 dtex with high contents of more than 50% PCM and with properties suitable for further textile processing. In spite of the high loading of the cellulose fiber with more than 50 % PCM it could be guaranteed that the PCM was strongly anchored in the cellulose structure. With the developed technology it is even possible to get fibers with a latent heat of more than 120 J/g in both pilot and production scale.

Finishing and dying of new fibers
Melt spun bi-component fibers
Laboratory dyeing and finishing experiments on fabrics made of bi-component filament yarns with PCM content were performed. Investigation of the dyeing process performance and study of the effects on the latent heat and the dimensional stability of the finished samples in washing were also made. Following the finishing procedures there was no evidence of latent heat loss in comparison with the untreated reference. A lower dyeability was observed in the case of both PET and PA6 fibers with PCM core as compared to samples without PCM. This is natural since the hydrophobic core material does not pick up dye stuff.

Wet spun cellulose fibers

Laboratory and pilot scale dyeing and finishing experiments on fabrics made of Lyocell fibers with PCM were performed to study the overall finishing processes influence on physical-mechanical characteristics, thermal properties, dyeability and color fastness properties. Pre-treatments in a single phase or mild alkaline or enzymatic treatments in successive phases are preferred for good results in terms of hydrophilicity, whiteness degree, dyeability and physical-mechanical characteristics of final product. Dyeing process can be done in a conventional way with good qualitative results in terms of tinctorial yield, evenness and color fastness. In the case of blends with PET, causticizing followed by bio-polish has no negative influence on the maximum force and abrasion resistance. Special care should be given to temperature and duration of drying and heat-setting operation to avoid loss of latent heat.

Physiological evaluation and thermal characterisation of garments with PCM

In the Noterefiga project the thermophysiological effect of the developed PCM garments were evaluated on 24 human subjects in controlled environmental conditions, see Figure 3.

Figure 3. Work Physiology Laboratory SINTEF. Evaluation of a jacket with integrated PCM during activity cycles (walking period). The subject is voting his perceived thermal sensation and comfort, while skin and core temperatures are continuously monitored.

A total of eighteen different garments were tested. As PCM has a potential stabilizing effect on body temperature, the principal hypotheses was that "PCM garments developed in the Noterefiga project will improve the wearer's thermal comfort during high and low work intensity and/or at varying ambient temperature". To investigate this, a number of different test protocols were developed for the different PCM garments. The criteria's for the test protocols was to mirror the actual use of the garment, simulate variations in work intensity (low/high) and/or environmental temperature (low/high). Our predictions have been that the PCM garments would stabilize skin temperature of selected skin areas and thus improve subjective thermal sensation and comfort during shift from high/low intensity and/or high/low ambient temperature.

Our studies demonstrated improved thermal comfort when wearing the melt spun PCM fiber in a warm environment. However, the cooling effect was relatively short lasting and a larger amount of PCM is desirable to extend the time of cooling. The Lyocell type PCM fiber demonstrated a stabilizing effect on the skin temperature when moving from warm ambient to cold ambient condition. This indicates that the PCM is absorbing heat from the body in the warm environment and releases the latent heat again when moving to the cold environment. The latent heat of fusion, melting/crystallization point, amount and distribution of PCM and design that allows for transport of moisture are all critical parameters for optimizing the thermoregulatory performance of PCM garments.

Project partners
Swerea IVF (coordinator, SE), Luxilon Industries (BE), SINTEF (NO), TITK (DE), Centexbel (BE), SmartFiber (DE), ADDCOMP Holland (NL), Technical University of Tampere (FI), Polisilk (ES), INCDTP (RO), Predilnica Litija (SI), Woolpower (SE) and FOV Fabrics (SE).