Transport properties and permeability of textile materials

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Abstract

Heat and mass transfer through textile fabrics play a crucial role in achieving optimal thermal comfort perception by a person. The governing properties of textile fabrics by which they influence heat and mass transfer from the human skin to the environment are thermal transport capacity, water vapor permeability, and air permeability. The transfer of liquid moisture through textiles is important for thermal comfort during frequent changes in physical activity or climate. Despite numerous studies on the transport properties of textile materials over the past years, investigation in this subject area is still needed. This special issue includes five articles that offer valuable information on the subject. Both commercial and specially designed textile structures were investigated within the presented studies with the ambitious goal of providing a new understanding of their transport properties. Within the first four papers presented, certain aspects of heat and mass transfer through textile materials were analyzed at the three scale levels: microscopic (fiber type), mesoscopic (yarn geometry and fineness), and macroscopic (fabric porosity) levels. The fifth article dealt with the influence of the seam type and the sewing thread fineness on the transport properties of the seamed structure.

Keywords: thermal comfort; air permeability; thermal insulation; moisture permeability; porosity.

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Comfort is a fundamental and universal need for a human being. Human perception of clothing comfort is a function of environment, garment, body, and psychological factors. Therefore, comfort is a multi-dimensional and complex phenomenon that is very difficult to define. According to a kind of universal definition, comfort is "a state of satisfaction indicating physiological, psychological, and physical balance among the person, his/her clothing, and his/her environment" [1]. The human body is a complicated thermodynamic system in which energy is produced by its metabolic activity and continuously dissipates into the environment to keep thermophysiological comfort, *i.e.* to achieve thermal equilibrium at normal body temperature with the minimum amount of bodily regulation (vasoconstriction, vasodilatation, sweating and shivering). The human perception of thermal comfort is the condition of the mind that expresses satisfaction with the absence of any unpleasant sensations of being too cool or warm or having too much perspiration on the skin. Being continuously in dynamic contact with the human body, clothing actively participates in the thermophysiological response of the human body, both to changes in physical activity and to changes in the environment. Therefore, clothing textiles' heat and mass transfer ability or transport properties are extremely important for a person's thermal comfort perception, allowing for the transfer of heat and perspiration generated by the body. The transport properties of textile materials include air permeability, water vapor permeability, and thermal transfer properties.

Efforts to achieve adequate transport properties of textile materials are mostly based on the engineering design of materials by adjusting their composition and geometrical structure achieved by the manufacturing methods and by the interaction of multi-scale (fiber, yarn, and fabric) hierarchical structure. Over the years, much research has been carried out to understand the transport properties of textile materials. However, considerable research efforts are still needed in this area to ascertain the explicit guidelines for the adequate design of clothing materials in terms of thermal comfort. Therefore, this special issue aims to contribute to these efforts by presenting new studies on the effects of material constituents (fiber, yarn, and fabric) on transport properties. The special issue consists of five articles. Two of them provide valuable insights into the understanding of heat transfer through specific textile fabrics. To fill the gap in the knowledge about the thermal behavior of rib knitted fabrics, Tasić *et al.* [2] investigated the thermal parameters of a range of rib knits differing in composition and knitting pattern. They attempted to establish explicit guidelines for

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engineering rib knits for socks based on end-use requirements. The study found that as the number of face loops on the technical face side of the knit increases, the coolness to the touch and thermal conductivity decreases. In addition, bamboo fiber has once again been proven suitable for hot climates.

Jacquard woven fabric refers to a specific woven structure that incorporates complex patterns directly into its weave rather than using printing or dyeing methods. The small number of studies on the transfer properties of jacquard woven fabrics inspired Kostajnšek and Bizjak [3] to investigate the influence of the size and distribution of the pattern and the type of weave (self-stitched double cloth, interchanging double cloth) on the thermal conductivity and air permeability of jacquard fabrics. The results reveal that the thermal conductivity of jacquard fabrics is affected by pattern size, with larger geometrical area leading to increased thermal conductivity. It has been shown in the study that the air permeability of jacquard fabrics is significantly influenced by the looseness of the weave, with the interchanging double weave being more permeable.

The water vapor permeability of clothing textiles refers to their ability to allow perspiration to pass through from the human body. Previous studies indicated water vapor diffusion as the dominant mechanism for moisture transport under steady-state conditions. The transfer of water vapor in fabric depends on the inter-yarn pores, as vapor can diffuse through air spaces in the fabric much faster than through the fibers themselves [4]. The research conducted by Tomovska *et al.* [5] specifically looked at the impact of biaxial extension on the water vapor permeability of polyamide pantyhose. Simulating the real wearing condition of the pantyhose, they found that for all extensions applied, the evaporative resistance significantly decreased as compared to the relaxed state due to enlarged inter-yarn pore size while stretching the knit. However, they also suggested that the linear density of the pantyhose's filament was responsible for the level of change in evaporative resistance with biaxial extension.

During high physical activity of a person when liquid perspiration is produced and needs to be transferred away from the skin to keep the thermal balance, the ability of next-to-skin garments to let the sweat pass through becomes essential for thermal comfort [6]. In this respect, Petrov *et al.* [7] evaluated the liquid management properties of an assortment of commercial knitted materials used for sport and leisure clothing. The knitted fabrics varied in fiber composition, mass per unit area, and porosity. It has been shown that the drying time of the samples correlates moderately with their mass and highly with their porosity. Considering the fact that modern sportswear garment is often made of several different textile materials, they suggest using pure polyester in garment areas that require quick drying. Being the most porous, it has a short drying time and the smallest wetting area.

Thermal comfort properties of textile materials are determined by fiber type (chemical and morphological specifications), physical and constructional properties of yarns and fabrics, and finishing treatment. Apart from these properties, garment design (in terms of style and design details) and fit can play a crucial role in achieving ideal thermal comfort [8]. Considering that the seam has a minimum of two layers of fabrics joined by sewing thread, assembling garment parts by using seems to produce the required design may affect the comfort properties of the garment. Maanvizhi *et al.* [9] investigated the effect of overlock and flatlock seam stitches, the most commonly used stitch types in active sportswear, on the transport properties of single jersey polyester seamed fabric. They also indicated the effect of sewing thread filament fineness on the heat and mass transfer through the seam structure.

We believe that the investigations presented in this special issue will enhance the current understanding of textile material transport properties, inspiring future research to improve clothing comfort.

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Transportna svojstva i propustljivost tekstilnih materijala

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Izvod

Sposobnost tekstilnih materijala da prenose toplotu i masu ima ključnu ulogu u obezbeđivanju optimalnog toplotnog komfora korisnika. Toplotna svojstva, propustljivost vazduha i vodene pare predstavljaju osnovne parametre tekstilnih materijala koji definišu njihovu sposobnost da prenose toplotu i masu. Često se kao četvrti parametar tekstilnih materijala ističe sposobnost prenosa tečnosti, koji uslovljava doživljaj toplotnog komfora pri čestim promenama nivoa fizičke aktivnosti i klimatskih uslova okruženja, kada dolazi do vremenskog zaostajanja u termoregulaciji ljudskog organizma. Uprkos brojnim istraživanjima transportnih svojstava tekstilnih materijala sprovedenih poslednjih godina, neophodna su dalja istraživanja u cilju uspostavljanja pouzdanih smernica inženjerskog dizajna odevnih tekstilnih materijala sa zadovoljavajućim svojstvima u pogledu toplotnog komfora. Stoga, ovo specijalno izdanje časopisa Hemijska industrija, koje obuhvata pet radova, ima za cilj da obezbedi dragocene informacije u ovoj oblasti. U okviru predstavljenih istraživanja, ispitivane su komercijalno dostupne ili posebno projektovane tekstilne strukture sa ambicioznim ciljem da se pruže nova saznanja o njihovim transportnim svojstvima. U okviru prva četiri rada razmatran je kompleksan uticaj hijerarhijske strukture tekstilnih materijala na njihova transportna svojstva, pri čemu su obuhvaćeni svi strukturni elementi: vlakna, pređe i tkanine (ili pletenine). Poslednji rad se odnosi na ispitivanje uticaja vrste šava i finoće šivaćeg konca na prenos toplote i mase kroz šavnu konstrukciju.

Ključne reči: toplotni komfor; propustljivost vazduha; termička izolacija; propustljivost vlage; poroznost