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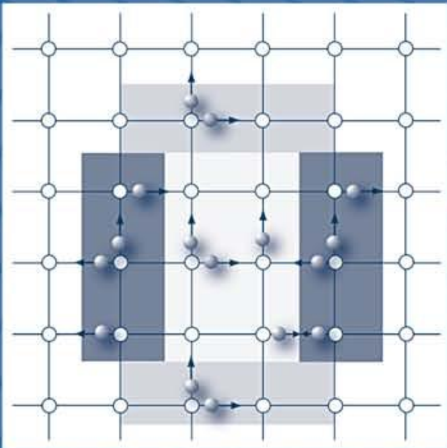

Thermal and moisture transport in fibrous materials

Edited by N. Pan and P. Gibson

The Textile Institute

Thermal and moisture transport in fibrous materials

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Contents

Contributor contact details

(* = main contact)

Editors

Dr Ning Pan
Division of Textiles and Clothing
University of California
One Shields Ave
Davis
CA 95616-8722
USA

E-mail: npan@ucdavis.edu

Phil Gibson
Macromolecular Science Team
AMSRD-NSC-SS-MS
Building 3 (Research)
Room 321
U.S. Army Soldier Systems Center
Natick
MA 01760-5020
USA

E-mail: Phillip.Gibson@us.army.mil

Chapters 1, 3, 6 and 7

Dr Ning Pan
Division of Textiles and Clothing
University of California
One Shields Ave
Davis
CA 95616-8722
USA

E-mail: npan@ucdavis.edu

Chapter 2

Professor David Lukas*
Katedra netkanych textilii
Technicka univerzita v Liberci
Halkova 6
Liberec 1
Czech Republic 461 17

E-mail: david.lukas@tul.cz
david.lukas@vslib.cz

Ing. Jiri Chaloupek
Katedra netkanych textilii
Technicka univerzita v Liberci
Halkova 6
Liberec 1
Czech Republic 461 17

E-mail: Jiri.Chaloupek@seznam.cz

Chapter 4

Wen Zhong
Department of Textile Sciences
University of Manitoba
Winnipeg
MB, R3T 2N2
Canada

E-mail: zhong@cc.umanitoba.ca

Chapter 5

R. S. Rengasamy
Department of Textile Technology
Indian Institute of Technology
Hauz Khas
New Delhi – 110 016
India

E-mail: rsr60@hotmail.com

Chapter 8

Professor N. Ghaddar
Department of Mechanical Engineering
Faculty of Engineering and Architecture
American University of Beirut
P.O. Box 11-236 - Riad El Solh
Beirut 1107 2020
Lebanon

E-mail: farah@aub.edu.lb

Chapter 9 and 15

Phil Gibson
Macromolecular Science Team
AMSRD-NSC-SS-MS
Building 3 (Research)
Room 321
U.S. Army Soldier Systems Center
Natick
MA 01760-5020
USA

E-mail: Phillip.Gibson@us.army.mil

Chapter 10

Professor David Lukas*
Katedra netkanych textilii
Technicka univerzita v Liberci
Halkova 6
Liberec 1
Czech Republic 461 17

E-mail: david.lukas@tul.cz
david.lukas@vslib.cz

Ing. Larisa Ocheretna
Doktorand
Katedra netkanych textilii
Technicka univerzita v Liberci
Halkova 6
Liberec 1
Czech Republic 461 17

E-mail: Ocheretna.L@seznam.cz

Chapters 11

Professor Kamel Ghali
Department of Mechanical Engineering
Beirut Arab University
New Road
Beirut
Lebanon

E-mail: amro@aub.edu.lb

Chapter 12

B. Jones
Engineering Experiment Station
Kansas State University
1048 Rathbone Hall
Manhattan
KS 66506-5202
USA

E-mail: jones@ksu.edu

Chapter 13

Jintu Fan
ST606
Institute of Textiles and Clothing
The Hong Kong Polytechnic
University
Hung Hom
Kowloon
Hong Kong

E-mail: tcfanjt@inet.polyu.edu.hk

Chapter 14

Professor David Lukas*
Technicka univerzita v Liberci
Halkova 6
Katedra netkanych textilii
Liberec 1
Czech Republic 461 17

E-mail: david.lukas@tul.cz
david.lukas@vslib.cz

Ing. Eva Kostakova
Doktorand/PhD
Katedra netkanych textilii
Technicka univerzita v Liberci
Halkova 6
Liberec 1
Czech Republic 461 17

E-mail: Eva.Kostakova@seznam.cz

Arindam Sarkar, MTech. (Indian
Institute of Technology, Delhi)
Doktorand
Technicka univerzita v Liberci
Halkova 6
Katedra netkanych textilii
Liberec, 1
Czech Republic 461 17

E-mail: sarkararindam@gmail.com

Chapter 16

Edward Arens*
Center for the Built Environment
University of California Berkeley
CA 94720
USA

E-mail: earens@berkeley.edu

Zhang Hui
Center for the Built Environment
University of California Berkeley
CA 94720
USA

E-mail: zhanghui@berkeley.edu

Introduction

In recent years, there has been a resurgence in the opportunities and challenges facing engineers, chemists, and textile scientists responsible for developing and applying new fiber-based materials. The explosive growth of manufactured nonwoven fibrous products, the continued development of textile processing technology, and the increasing applications of nanotechnology in the form of nanoparticles and nanofibers incorporated into fibrous materials have all led to the need for new approaches to characterize the behavior of these materials.

The role of heat and mass transfer is often critical to the manufacture or function of devices, structures, and engineered items incorporating fibrous materials. Two aspects of thermal and moisture transport in fibrous materials are examined in this book: the basic nature of the transport process itself and the engineering factors important to the performance of manufactured articles incorporating fibrous materials.

The purpose of this book is to survey the present state of the art with respect to the engineering and scientific aspects of heat and mass transfer through fibrous materials. Research on these materials is driven by the needs of industry to develop functional materials that perform well in their intended application. A welcome trend in recent years is to look outside of the textile research community to other engineering fields for insights into the properties of this unique class of engineering materials. The general treatment of fiber- and textile-based materials as a soft, porous, deformable, multi-component matrix has equivalent applications in materials and fields such as particulates (soil and sand), composites, food, and biomaterials.

The general approach of this book is to treat fibrous materials as 'soft condensed matter' in the jargon of physics, even though for many the term fibrous material is a little exotic already. However, this classification has many positive implications for the manufacture, use, and performance of these materials in that they will be just as rigorously studied as any other counterparts of engineering materials under the blessing of being a member of the group; something that has never happened systematically before. Many of the chapters in this book treat fibrous materials as a porous media – a solid material phase permeated by an interconnected network of pores (voids) filled with fluids (liquid or gas). The solid matrix and the pore spaces are assumed to form two interpenetrating phases, which may be either continuous or discontinuous.

The coverage of chapters emphasizes heat and mass transfer, with mass transfer referring primarily to fluids such as gases, vapors, and liquids in continuous phases. A significant area of mass transfer that is missing from this book is particle filtration, a topic, albeit very interesting and technologically important, outside the scope of this book.

The chapters in this book comprise an eclectic mix of applied, theoretical, and engineering-oriented approaches to the problem of heat and mass transfer in fibrous materials. The varied perspectives are valuable. Some of the physics-based approaches provide a fundamental framework for understanding the interactions between the various elements of a fibrous 'system' of polymer fibers, pore spaces, liquids, and gases. Other chapters provide excellent applied examples that illuminate the factors contributing to the performance of a fiber-based product (such as a clothing system).

More specifically, the first major issue is the description or characterization of fibrous materials, and this is covered by the first couple of chapters in the book. Nearly all the new challenges in dealing with transport phenomena in fibrous materials can be traced back to the complexities of the fibrous structures: we cannot even define such a simple physical quantity as the density of fibrous materials without running into the problem of the state of the material (fiber packing, volume fraction, etc.) How can we apply PDEs to a material system for which we even cannot define where the material boundary is? How to conveniently specify the fibrous materials and consequently incorporate the information into various governing equations would be, arguably, the most challenging problem.

Another most interesting characteristic of fibrous materials is that the solid matrix is often a participating media in the overall transport process. Many treatments of transport phenomena in porous media (such as geology) treat the solid matrix as an inert space-filling substance that does not participate in mass transport other than defining the geometry of the pores. Even in heat transfer analyses, the solid matrix is often given a defined thermal conductivity, and is neglected or ignored in favor of the transport phenomena taking place in the fluid contained in the pore spaces. A deformable solid matrix composed of polymeric fibers requires that more attention be paid to the solid portion of the porous material model. Fibers can absorb the vapor or liquid phase, causing the fibers to swell or shrink. The entire porous material can be easily deformed under mechanical stress, changing such characteristics as porosity, and perhaps expelling or taking up more liquid or gas into the porous structure. Coupling phenomena between heat and mass transfer, or between mechanical stress and heat/mass transfer, can make a full analysis and simulation of the behavior of a fibrous polymeric material extremely complicated, particularly when various liquid and vapor components are involved. Some bold and insightful attempts in tackling the problem are reported in several chapters with more detailed deliberations.

The intriguing nature of the issues in fibrous materials calls for powerful tools, and computer modeling is the most robust available: it is even able to take the structural irregularities into account. There are various ways computers can help unravel the mysteries surrounding the material, such as numerical solutions of otherwise intractable governing equations, discrete simulations using lattice or cellular automate approaches or stochastic algorithms based on thermodynamics and statistical mechanics. There are two chapters solely devoted to this topic.

A few of the chapters delve into approaches and disciplines that have not yet been applied widely to the science and technology of fibrous materials, but which may provide inspiration for extending the formalism of techniques such as stereology and lattice methods to further application in this field.

Another difficult area is dealing with the interfacing between fibrous materials (clothing in this case) and the human body, which is the main incentive in studying such a *heat-moisture–swelling fiber* complex. Our exploration in this area should not end at the manikins and we have to examine more intimately the interactions between clothing and the human body to make more sense out of this complex system. We have one whole chapter, as well as several sections spread over other individual chapters, introducing the human physiology relating to or determining skin–clothing interactions. We are in fact very pleased to have included such a component in this book, for it is very likely that nano-science, computer modeling and human physiology may revitalize textile science as a whole.

N. Pan and P. Gibson