STUDIES ON THERMAL TRANSMISSION PROPERTIES OF FABRICS

by

DEBARATI BHATTACHARJEE
Department of Textile Technology

Submitted
In fulfillment of the requirements of the degree of
DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI
NEW DELHI, INDIA
MAY – 2007

Textile Fiber - Thermal Properties

CERTIFICATE

This is to certify that the thesis titled "Studies on Thermal Transmission Properties of Fabrics", being submitted by Mrs. Debarati Bhattacharjee to the Indian Institute of Technology, Delhi, for the award of the degree of Doctor of Philosophy, is a record of bonafide research work carried out by her. She has worked under my guidance and supervision and fulfilled the requirements for the submission of the thesis, which has attained the standard required for a Ph.D degree of this institute.

The results contained in this thesis have not been submitted, in part or in full, to any other university or institute for the award of any degree or diploma.

Dr. V. K Kothari

Professor
Department of Textile Technology,
Indian Institute of Technology, Delhi,
New Delhi - 110016,
India

ACKNOWLEDGEMENTS

I begin by thanking my research supervisor, Prof. V.K. Kothari, who first encouraged me to take up this topic for my thesis, and provided continuous guidance and support throughout the course of the work. It has been a privilege for me to work with him all these years and learn so much from him, in academics as well as in personal life. I am also grateful to Prof. S. R Kale, Deptt. of Mechanical Engineering, IIT Delhi, who always had time to help me with the intricacies of thermal engineering, statistical analysis and computational fluid dynamics. He meticulously went through my work from time to time to point out the major errors. I also thank Prof. L. Hes, Technical University of Liberec, Czech Republic, for being at IIT Delhi during the early stages of the existence of "Comfort Lab" and helping us in setting up the instruments and in repairing the minor and major glitches, Prof. S.M Ishtiaque, Dr. R Alagirusamy, and Dr. A. Das for allowing me to use all the facilities available in the department and giving permission to work according to my own schedule in the department at odd hours. I also thank Professors P.K Banerjee and R Chattopadhyay for providing the well needed 'pep talks' from time to time.

I thank Dr. K.U Bhasker Rao, Director, DMSRDE, Kanpur for allowing me to continue my research work after joining DRDO as a scientist. My heartfelt gratitude goes to Dr. Anurag Srivastava, Scientist 'E' and Head, Textiles Division, DMSRDE for his continuous support and smoothening a lot of hurdles during the last stages of the thesis.

I thank the staff members of all the laboratories of the Department of Textile Technology, IIT Delhi, for extending a helping hand whenever needed.

This work would not have started if I hadn't obtained the fabrics for various studies at the first place. I am grateful to Mr. A.K Basu, G.M (Technical) (Vardhman Group) and Dr. Naresh Tyagi (Wills Lifestyle, ITC Group), for arranging various fabrics samples used in the study.

I want to acknowledge a few of the numerous people who have gone out of their way and helped me during all these years. Dr. Abhijeet M. Vaidya for teaching FLUENT, Dr. Anirban Guha and Vijay Yadav for helping with ANNs and computing techniques, Dr. Krishna Kumari Singh for helping with various MATLAB toolboxes, Dr. Anindya Ghosh for being an enthusiastic and extremely helpful participant during numerous discussions on statistics, mathematical modeling and life in general.

Keeping my composure through all these years would not have been possible without the aid of friends. I am grateful to all my friends at IIT Delhi, Kailash House and DMSRDE for helping me keep a high morale whenever I needed. I would like to specially mention Kausik Bal and Brojeswari Das who have been such wonderful lab mates for last 3 years, Dr. Rashmi Rekha Devi and Amrita Vatsa for taking charge of my home during the thesis writing days and nights. A special mention to Jorge Cham and his creations, who have been an integral part of my daily schedule all these years.

My life wouldn't have been as wonderful if it wasn't for my parents and parents-in-law, my sister, Nandini and brother-in-law, Rajib. They have been great supporters in all the decisions I have taken and always had faith in me. Finally, I thank my best friend, my husband, Munish, for being my pillar of support, hope and love.

In the end, I would like to thank all the wonderful people with whom I have come in contact during the years of my research.

Debarati Bhattacharjee

May 14, 2007

ABSTRACT

Prediction of thermal properties of textile materials has always been an issue of concern for the characterization of clothing comfort as well as designing of textile materials for specific insulation applications. A number of investigations have been carried out to understand the phenomenon of heat transfer through fabrics. The effects of fabric and fibre properties and the environmental parameters on the thermal insulation properties have been studied by many researchers. Many methods of measurement have been devised to measure the thermal insulation of textile materials in different conditions. Prediction tools that can be used to estimate the thermal insulation of fabrics prior to their manufacture can greatly decrease the time taken to design a clothing assembly. However, a comparative analysis of different prediction tools available at present that can be used for the prediction of thermal properties has not been reported. A comparative study of different prediction models for thermal insulation based on constructional parameters of fabrics has been carried out to see which model gives the best prediction performance with least errors.

The focus of this thesis is to analyse various models that can be used to predict the thermal resistance of a woven fabric based on its basic constructional parameters. The fabric parameters considered were weave, warp and weft linear density, thread spacing, thickness and fabric weight. The last two parameters, although derived properties, have been reported to have a major influence the thermal resistance of the fabrics. Hence, inclusion of these two properties was necessary. Different methods of prediction, mainly statistical modelling and artificial neural networks were used to check their capability to estimate the thermal resistance of the same set of woven fabrics and compare the prediction performance of both these tools. It was not possible to segregate the constructional parameters and find their individual effect on the thermal resistance because

they are all inter-related to each other. It was observed that the thermal properties of fabrics are based on the collective influence of all the constructional parameters instead of one or two. A polynomial function including all the parameters as variables and consisting of linear, interactive and square terms gave the best prediction. A feed forward back propagation neural network with two hidden layers was designed with the constructional parameters as inputs and thermal resistance as output. It was seen that the neural network was able to predict the steady state thermal resistance value of the fabrics with excellent correlation and less error as compared to the statistical model.

A conduction-radiation model of heat transfer through woven fabrics was developed based on the first principles. The basic weaves can be converted into a common structure consisting of unsupported lengths of warp and weft, stack of warp and weft and air pore. This structure can be used to find the conduction heat transfer by lumped method. The radiation heat transfer through this structure was divided into two parts viz. heat transfer through air pores which can be calculated by net radiation method in an enclosed surface and secondly heat transfer through the fibrous web which can solved with the help of linear anisotropic scattering through a web of infinite cylinders. A MATLAB based code was generated which could predict the thermal resistance of basic woven fabrics based on their constructional parameters. The values obtained from this program were compared with the actual experimental values and it was observed that the mathematical model was able to predict the thermal insulation of woven fabrics in a non-convective environment.

Convection heat transfer over the fabric at different velocities through the wind tunnel could be simulated with the help of computational fluid dynamics. The effect of various fabric parameters like fabric porosity and thickness and environmental parameters like air velocity on the convective heat losses was studied. It was observed that the convection heat transfer increases with increase in air velocity. The convective heat transfer decreases with the increase in the fabric thickness and also with increase in fabric porosity. The latter was an interesting and contradictory observation and it was suggested that in the case of fabrics placed in a direction parallel to the wind flow, increase in porosity means increase the air pores inside in the fabric which act as insulators and the thermal resistance is increased. The mathematical model along with the values obtained from the computational fluid dynamics was used to predict the thermal insulation of fabrics, in natural as well as forced convective modes and the values obtained thereof compared well with the experimental data.

Contents

Appendices