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An Inverse Problem of Textile Materials Determination under Low Temperature

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Abstract

Based on the model of steady-state heat and moisture transfer through textiles, an Inverse Problem of Bilayer Textile Materials Determination (IPTMD) under low temperature is presented. According to the idea of regularization method, the IPTMD can be formulated into a function minimization problem. Combining the finite difference algorithm for nonlinear ordinary differential equation with direct search method of one-dimensional minimization problems, an iterative algorithm for the regularized solution of the inverse problem is constructed. By analyzing the results of numerical simulation of different climate clothing, some conclusions are obtained: Hooke-Jevees direct search method can solve the inverse problem of bilayer textile materials determination, numerical simulation also shows the effectiveness of algorithm and the rationality of the proposed inverse problem, most importantly, the results can give some scientific explanations for experiments with the textile materials.

Keywords: Bilayer Textile Materials; Heat and Moisture Transfer; Type Design; Inverse Problems; Regularization Method; Numerical Solution

1 Introduction

The phenomena of coupled heat and mass transfer in capillary porous media has been drawing greater attention of research groups because of its importance in practical applications, such as civil engineering, energy storage and conservation, as well as functional clothing design. For example, as for the functional clothing design, there are many requirements on human body comfort, and people should develop healthier and safer textile based on heat and mass transfer characteristics.

In practical applications, the mathematical modeling and numerical simulation becomes much more important since it provides an efficient way for evaluating new designs or testing new

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materials. Meanwhile, the research results are necessary fundamentals to theoretical support and scientific explanations for textile materials design experiments. From 1930s, researchers discussed a few models of heat and moisture transfer and corresponding numerical simulations of thermal and water vapor concentration in porous media [1-12].

Henry first proposed a mathematical model for describing heat and moisture transfer in textiles in 1939 [1] and further analyzed the model in 1948 [2]. After his work, some coupled models of heat and moisture transfer were established or developed on the basis of ordinary differential equations in [11, 12] or partial differential equations in [1-10]. Some researchers, such as Y.Li and J.T.Fan, presented a few mathematical models of coupled heat and moisture transfer through porous clothing assemblies and porous insulation. Based on these models, they designed different numerical methods to solve these problems, such as finite difference method, finite volume method, finite element method and controllability volume time domain recursive method, and the numerical results were well matched with experimental results [3-10].

The computation of temperature and moisture content fields in porous media, from the knowledge of initial and boundary conditions, as well as of the thermo physical properties appearing in the formulation, constitutes a direct problem of heat and mass transfer. On the other hand, the simultaneous estimation of thermo-physical parameters that appear in heat and moisture transfer in textiles, by using temperature and moisture in the medium and environmental temperature and humidity people live in and the comfort index of clothing is an inverse problem of coupled heat and mass transfer.

The inverse problems of textile materials design on heat and moisture transfer properties are important and indispensible in application. By using the theories and methods of inverse problem to study textile materials design, it can scientifically predict and guide the textile design and clothing equipment design, at the same time; it can also have significances for the development of advanced textile materials and protecting human heath in harsh environment.

Recently, D. H. Xu studied the model of stationary heat and moisture transfer through parallel pore textiles by means of theoretical analysis and numerical simula- tions [11, 15]. Based on the model, the formulation of inverse problems of textile materials determination for single-layer and bilayer textile materials under low temperature were presented and different numerical methods were applied to solve these inverse problems, such as Hooke-Jevees's pattern search method, Golden section method and the other direct search method [13, 14].

In this paper, we extend our previous works [14] and propose an Inverse Problem of Bilayer Textile Materials Determination (IPTMD) under low temperature, that is to say, according to the environment's temperature and humidity people live in and the comfort index of clothing, from the knowledge of the textile geometry structure and thickness of the inner and outer material, as well as the heat conductivity of inner textile material, we shall determine the type of the outer material.

The paper is composed of the following sections: In Section 2, a mathematical model of steady-state coupled heat and moisture transfer through parallel pore bilayer textiles will be introduced. In Section 3, based on the model of in Section 2, an Inverse Problem of Bilayer Textile Materials Determination (IPTMD) under low temperature is presented. In Section 4, by using the finite difference method, numerical computation of the direct problem is obtained. In Section 5, according to the idea of regularization methods, we establish iteration schemes to numerically solve