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Simultaneously Reconstruction of Radiation-Conduction Properties of Nanomaterial Thermal Insulators with Particle Swarm Optimization Algorithm

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ABSTRACT: In this paper, an optimization algorithm is proposed to simultaneously reconstruct radiation and conduction properties for thermal insulators constructed from Nanomaterial between two flat plates. The radiation problem is modeled using modified discrete ordinates method. The conduction and radiation problems are solved using the finite volume method and the inverse problem is solved using the particle swarm optimization problem. The various cases have been solved in this paper. Firstly a simple problem designs and solves. Next, a multi-stage algorithm with new objective functions is used for reconstruction of dependent-temperature properties of a nanomaterial. In the first case, constant absorption coefficient is reconstructed using the radiation intensity of boundaries, in the first stage and constant conduction-radiation parameter is reconstructed using the surface total heat flux in second stage. In the second section, the competency of the proposed multi-stage algorithm for the radiation and conduction temperature-dependent parameters is tested. In the numerical test a thermal insulator constructed from nanomaterial with 1cm thickness is used. The proposed algorithm and new objective functions are presented in this section to decrease sensitivity of Plank number and optical thickness to the measurement error.

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1- Introduction

The solution of inverse problems in heat transfer has great importance. Yatoren et al. [1] recovered the conductivity and temperature-varying linear absorption coefficients using Particle Swarm Optimization (PSO) Algorithm in a one-dimensional time-dependent conduction-radiation medium. In the governing equations, they assumed that thermal conductivity was only a function of temperature and was not dependent on a location and used a simplified form of the energy equation. San [2] recovered the thermal conductivity, absorption coefficient and scattering coefficient using a multi-stage optimization method in a semi-transparent adsorbent and two-dimensional emitter medium with conduction-radiation heat transfer, absorption coefficient and scattering coefficient, all of which were considered constant. In this paper, the nonlinear functions of radiative-conductive properties are intended for the reconstruction. Therefore, a multi-stage algorithm based on the PSO Algorithm and new objective functions is presented to reduce the error in the reconstruction of the results. The direct solution of the radiation heat transfer equation is formulated using the Modified Discrete Ordinates Method (MDOM) and is solved by the Finite Volume Method (FVM). The energy equation is also discretized with the finite volume method. The PSO algorithm has been used to solve inverse problem.

2- Problem Definition and Solution Method

Consider a one-dimensional medium with conduction - radiation heat transfer type according to Fig. 1. The black walls are placed at a constant temperature. Gray medium is considered without distortion. It is assumed that all properties and values of flux and radiation intensity on the boundaries can be measured. The distance between two plates is L. The purpose of the problem is to calculate all the temperature-varying conductivity and radiative properties between the plates.

The dimensionless energy equation for a conduction-radiation heat transfer medium with a temperature-varying

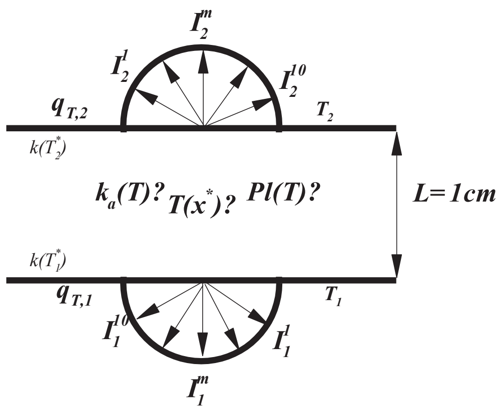

Fig. 1. Schematic figure of the present work

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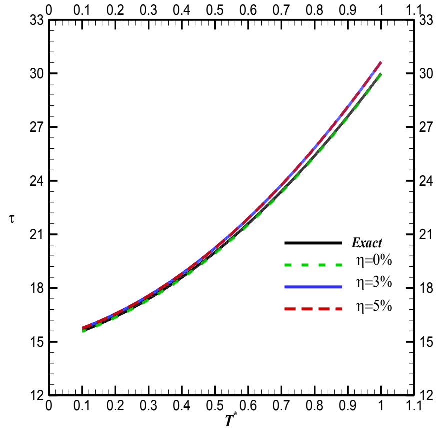

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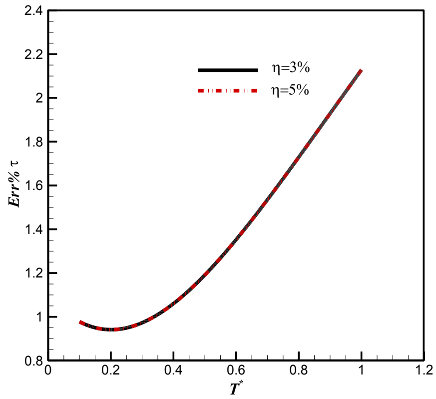

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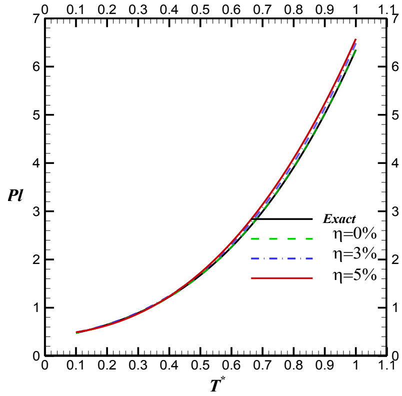
Fig. 2. Results of optical depth reconstruction a) Accurate and reconstructed optical depth distributions for applied errors of 3% and 5% b) Error distributions of optical depth for 3% and 5% modes



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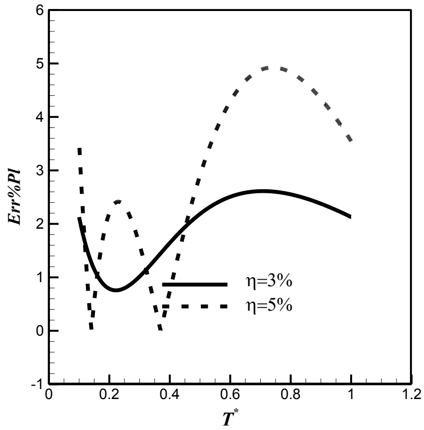

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Fig. 3. Thermal conductivity reconstruction results a) Planck distributions for 3 accurate and reconstructed states with three measurement errors of 0%, 3%, and 5%; b) Relative error distribution diagram for the Planck number after reconstruction for applied errors of 3% and 5%.

thermal conductivity in steady-state is presented in Eq. (1).

$$\frac{d}{dx^*}\left(Pl(T^*)\frac{dT^*}{dx^*}\right)-\frac{dq^*_r}{dx^*}=0 \quad (1)$$

In order to solve the radiation intensity equation, the MDOM is used in accordance with the Ref. [3]. The dimensionless radiative heat transfer equation for a ray is as Eq. (2)

$$\frac{dI^*}{dx^*}=-\beta(T^*)I^*(\Omega)L+k_a(T^*)LT^{*4}+\frac{\sigma_s L}{4\pi}\int_{\Omega'=4\pi} I^*(\Omega')\phi(\Omega',\Omega)d\Omega' \quad (2)$$

In this equation, $k_a(T^*)$ is the absorption coefficient and σ_s is the scattering coefficient.

3- Results and Discussion

In this part, a thermal insulator made of nanomaterials is intended. In order to consider a real-mode construction and testing in the laboratory, an insulator with a thickness of 1 cm is intended. Thermal insulators made of nanomaterials have high absorption coefficients and low conductivity coefficients. Thus, low heat flux and radiation intensity go out of boundaries. In addition, the values of radiation intensities in different directions have no significant changes. Therefore, the values in the boundaries alone are not enough for the suitable reconstruction of properties. In order to solve the problem in this section, in addition to using a two-step algorithm with discrete objective functions, new objective functions are applied at each stage for use in the reconstruction of properties of such materials.

Planck considered is in accordance with Eq. (3).

$$Pl=3.53T^{*3}+1.41T^{2*}+1.058T^*+0.353 \quad (3)$$

The optical depth considered is in accordance with Eq. (4).

$$\tau = 10T^{*2} + 5T^{*} + 15 \quad (4)$$

3- 1- Solving Algorithm:

Step 1: Using the objective functions of output total radiation intensity of the surface ($G'1$), the Planck number of surfaces (G3) and the heat flux of the entire surfaces (G2), recover all the coefficients of the optical depth and Planck equation.

Step 2: Put the Planck equation coefficients obtained from step 1 as the known parameters, and then recover the coefficients of the optical depth equation by using the objective function of the total radiation intensity of the surface output and Planck surfaces. The results of optical depth reconstruction are as follows.

4- Conclusions

To reconstruct the properties varying with the temperature of this medium, for the absorption and conduction coefficients, two new objective functions were defined for use in a two-step algorithm. In this section, it was proposed for the first stage of the algorithm that the objective function of the total radiation intensity of the boundaries and the overall heat flux and the conductivity coefficients of the material at the boundary temperature to be used. The result of this step was the reconstruction of the coefficients of the Planck number equation. Then, in order to reconstruct the coefficients of the absorption coefficient equation, the total objective functions of the output radiation intensities of the boundaries and the boundary conductivity coefficient at the surface temperature were used. The reconstruction results were in good agreement with the exact results, even with measurement error of 5%.

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