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Inverse estimation of boundary conditions on radiant enclosures by temperature measurement on a solid object ☆

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ABSTRACT

In this paper, we present an inverse analysis to estimate the thermal boundary conditions over a two-dimensional radiant enclosure from the knowledge of the measured temperatures for some points on a solid object within the enclosure. The conduction heat transfer in the solid object and the radiative heat transfer between the surface elements of the enclosure are formulated by the finite volume method and the net radiative method, respectively. The resultant set of nonlinear equations is solved by the Newton's method. The inverse problem for estimation of boundary conditions over the radiant enclosure is solved by the conjugate gradient method.

1. Introduction

Inverse heat transfer problems are concerned with the determination of the thermal properties, the initial condition, the boundary conditions, and the strength of heat source from the knowledge of the temperature or heat flux measurements taken at the interior or the boundary points of the domain. They have been widely used in many design and manufacturing applications, especially when direct measurements of the surface condition are not possible. Many studies of the inverse problems with conduction, convection and radiation have been reported [1–16]. Inverse problems have also received much attention in recent years for the cases with multimode heat transfer [17–22]. A comprehensive study of inverse heat transfer problems has been reported in [23].

In the present work, we deal with the inverse problem of estimating the boundary conditions over the boundary surface of a radiant enclosure by measuring the temperatures of some points on a solid object within the enclosure. The applications may be seen in manufacturing, thermal treatment and food industries where we are interested to know the strength of radiant heaters located on the wall surface of the radiant oven by the measurement of temperatures over some points of product surface. Heat is transferred in the solid object by conduction, and the dominant mode of heat transfer in the enclosure is radiation. The solid object is subdivided into control volumes and the boundary surface of the solid object and the radiant enclosure are subdivided into surface elements. For the direct problem, the conduction heat transfer in the solid object is formulated by the finite volume method, and the radiation heat transfer between surface elements are formulated by the net radiation method. The complete set of nonlinear equations is then solved by Newton's method. For the inverse problem, the temperature distribution over some parts of boundary surface of the radiant enclosure is regarded as unknown, and the temperatures for some sampling points over the solid object are considered to be available by the measurement. The conjugate gradient method is used for minimization of the objective function which is defined as the sum of square deviations between the measured and estimated values of temperatures on the solid object. Finally, the performance and the accuracy of the present method for recovering the boundary temperature distribution over the radiant enclosure from the knowledge of measured temperatures of solid object is examined by considering some examples with different temperature distributions over the radiant enclosure. The effects of the location of solid object within the enclosure, and noisy input data on the accuracy of the inverse solution are investigated by several numerical experiments.

2. Description of problem

Consider a two-dimensional square enclosure A, and the square solid object B within it, as depicted in Fig. 1. All the internal walls of the enclosure A, and the boundary surfaces of the solid object B are diffuse-gray. The enclosure filled with a transparent medium. All the thermal properties are assumed to be constant. Heat is transferred by radiation throughout the enclosure A, and is transferred in the solid object B with conduction. The side walls of the enclosure are at constant temperature of $T_s = 300\,\mathrm{K}$ and the top wall of the enclosure is kept insulated. No boundary condition is specified over the bottom wall of the enclosure. The aim of the inverse problem is to find the boundary conditions over the bottom wall of the enclosure

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