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Geometric optimization of a radiation–conduction heating device using meshless method

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A B S T R A C T

A new optimization design methodology which combines direct collocation meshless method with the conjugate gradient method is presented to conduct geometric optimization for heating devices with considering coupled conductive and radiative heat transfer. To avoid the tedious meshing and remeshing of the variable computational domain in the inverse design process, the direct collocation meshless method is adopted to deal with energy conservation equation including conduction and radiation. The modified conjugate gradient method is used to obtain the optimum geometric shape of the heating device. The design requirement of the pre-specified total heat flux distribution on the pre-appointed region of heated surface is satisfied by adjusting the height of the adiabatic reflection surfaces and the geometric shape of the heating surface. A typical test example is studied to illustrate and verify the optimization design methods. The optimizated design results show that the desired design requirement could be successfully achieved by using the present inverse design methodology.

1. Introduction

Radiation combined with other kinds of heat transfer in semi-transparent media are very important in high temperature devices. The combined heat transfer mode [1,2] has been widely presented in many modern high temperature industrial processes. Differing from the traditional high temperature heating devices, the modern high temperature industrial processes require some special surfaces of the heating device to meet the pre-specified temperature or heat flux distribution accurately [3–5]. For the conventional trial-and-error design method, it is hard to complete the optimization design for the modern high temperature heating device.

In recent years, the inverse design techniques [6–11] have received much attention and have been widely applied in designing the high temperature device. Being different from the traditional forward "trial-and-error" design method, an objective function is defined according to the design requirement, the optimization techniques and the iterative process are used to minimize the objective function and achieve the best final design result. Daun and Howell [3] investigated two inverse techniques for the design of radiative transfer systems, one is to transform the inverse problem into a minimization problem, another is to solve the problem explicitly using regularization, specifically, a two-dimensional diffuse-walled radiant enclosure is used as a design sample.

Currently, more attention are paid on how to meet the design requirement accurately, such as the pre-specified temperature or heat flux distribution on some special surfaces in high temperature device. Generally, these kinds of design requirements can be satisfied by two different ways. One is the inverse boundary condition design, the other is inverse geometric shape design. For the inverse boundary condition design, the shape of the enclosure is given, and the design task is to determine the proper boundary conditions (heat flux or temperature) on some specified surfaces to satisfy the design requirement. Many researches were concerned on this kind of boundary condition design. França et al. [4] investigated the inverse boundary design for an enclosure with combined-mode heat transfer of radiation, convection and conduction. A proper heat flux distribution was imposed on the heating surface to satisfy the prescribed temperature distribution and heat flux distribution on design surface. Mossi et al. [5] considered an inverse boundary condition design problem which involves radiation and convection heat transfer. The desired temperature distribution and heat flux distribution on design surface were met by finding proper heat flux distribution on the heating surfaces located on the top and side walls. Kim et al. [12] made a comprehensive study on inverse radiation–conduction design problem in a participating concentric cylindrical medium.

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