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Numerical study on the optical and radiative properties of the gradually-varied volumetric solar receiver

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Abstract

The volumetric solar receiver is one important component of the Concentrated Solar Power (CSP) system. In this paper, a gradually-varied volumetric solar receiver is proposed. Based on a modified random generation method, a 3D model of this type of solar receiver is reconstructed. With the use of Monte Carlo Ray Tracing method (MCRT), the optical and radiative properties of this novel structure are investigated. The result shows that the radiative heat loss could be reduced owing to the lower reflectivity of this novel structure. It also outperforms in the photon absorption compared with the uniform structures that was examined in this paper. Furthermore, a more ideal photon distribution inside the structure is exhibited by the gradually-varied volumetric solar receiver.

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Keywords: Gradually-varied volumetric solar receiver; Reconstruction; MCRT; Optical properties; Radiative properties

1. Introduction

Facing with the problems of the paucity of fossil fuels and the aggravation of the greenhouse effect, harvest and use of renewable energy has drawn much attention in recent years. Among various renewable energy technologies, Concentrated Solar Power (CSP) offers one of the major solutions to the above-mentioned problems, due to the use of the unlimited resource of solar power.

As one of the important components of a CSP system, solar receiver, especially the volumetric solar receiver has been widely studied. In the study of Kribus [1], the so-called "volumetric effect" is defined as the existence of ideal temperature distribution and low front surface temperature. Numerical study conducted by Kribus [1] indicated that higher porosity and smaller pore size tend to enhance this effect.

Apart from the uniform structure, new types of receivers have been investigated. Fend et al. [2] had put

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forward a double-layer silicon carbide foam which consists a high cell density (80 PPI) in the front layer and low cell density (20 PPI) in the rear. Similar idea could be found in the patent [3], which proposed a solar receiver that has a graded porosity where the porosity of front part is higher than that of the rear part.

The impact of abrupt change of porosity has not been taken into consideration in these studies. More studies and profound understanding is necessary to reveal the optical and radiative properties of this type of structure of the receiver. Therefore, a gradually-varied volumetric solar receiver is proposed. A major feature of this new idea lies on the variation of porosity, which decreases gradually from the front surface to the rear surface. In this paper, the modified random generation method and MCRT method are applied to fully reveal the properties of this novel structure.

2. Structure reconstruction

2.1. Reconstruction process

Before studying the optical and radiative properties, the geometrical model of the object needs to be firstly reconstructed. Intensive studies have been carried out by different researchers to reconstruct the porous structure. Three main methods have been employed in different studies: X-ray tomography [4], the periodic generation-based technique [5] and the stochastic method [6].

In this paper, the proposed method - modified random generation method is based on the method employed by Kırca [6]. The flowchart (see Figure 1) elaborates the whole process to reconstruct this novel structure. The essential is to divide the whole structure into sufficient number of sub-layers. The porosity in each layer is set as constant, but it changes gradually from layer to layer from the viewpoint of the whole structure. A sufficient number of layers are sliced so that the change of porosity is gradual.

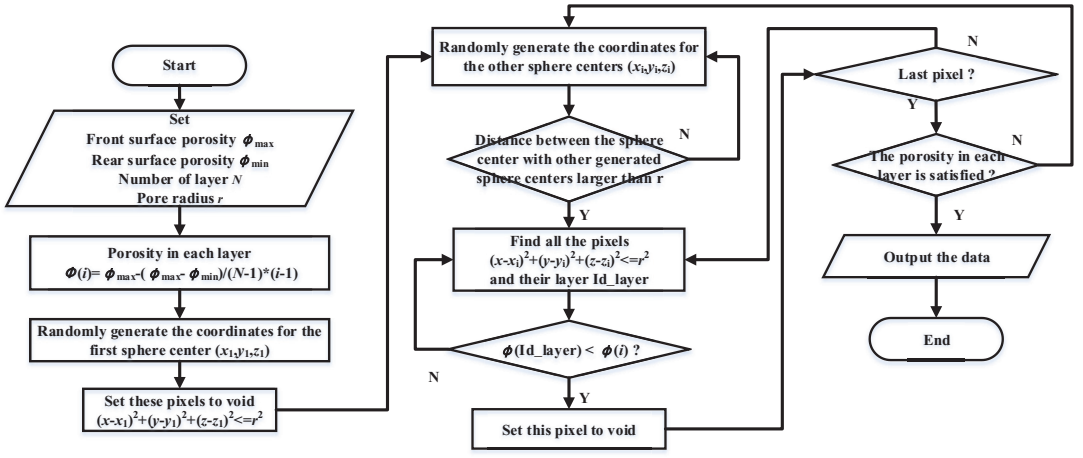

Fig. 1. Process flowchart for the structure reconstruction

2.2. Computational model

The computational model in this paper deals with a domain of the size of 1.0×1.0×1.0 cm. The porosity changes linearly along the coordinate axis x (incident direction), from 0.95 in the front of the structure to 0.65 in the rear. The pore diameter is set to 1 mm, and the whole structure is divided into fifty sub-layers along the coordinate axis x, which is sufficiently fine. Figure 2 shows the front view and the back view of the described structure, respectively.