Heat transfer performance evaluation of a large-size cavity receiver in the solar power tower plant based on angle factors

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Abstract

The thermal performance of a cavity receiver in the solar tower power plant crucially relies on the spatial relationship of its polyhedral geometric inner surfaces. So far, it has always been a focus to propose a model coupling the convection and radiation heat transfer for a large-size receiver. Based on the net energy exchange and thermal equilibrium principle, a radiation heat transfer model in terms of the angle factor equations of inner surfaces in the receiver was developed in this work. The finite difference method with an automatic mesh generation technique was employed to disperse the angle factor equations of inner surfaces in the receiver. Consequently, the thermal performance of the cavity receiver was evaluated while convection heat transfer between the receiver inner surfaces and ambient air was to consider with the available convection correlation. The results showed that the thermal efficiency of the cavity receiver increased with the increase of incident heat flux. When the width-depth ratio decreased, the cavity efficiency increased first and then decreased. With regard to different receiver structure parameters, the total heat loss of the receiver varied differently with the increase of the heat absorption area to the aperture area ratio. Meanwhile, the design of the cavity receiver structure in the MW solar power tower plant in Yanqing, Beijing was optimized according to the model proposed.

1. Introduction

During the past several decades, the solar tower power technology was widely approved to be feasible due to its comprehensive superiority on higher efficiency, relatively lower capital cost and longer campaign life. As one of significant components of this Concentrating Solar Power technology (CSP), the cavity receiver can directly determine the safety, stability and economy of the whole tower power system. However, since the large-scale dimension of the receiver and the high concentrated solar flux on it, there is a complex heat transfer process involved in radiation, convection and conduction in the receiver. These heat transfer processes can strongly affect the thermal performance of cavity receivers. Referring to the available investigations, the primary study of cavity receivers has been focused on the convection and radiation heat transfer process. Much work has been done on convection heat transfer in solar cavity receivers, some promising results by which already has been obtained. The analysis model was provided by Clausing (1981) to assess the convection heat transfer, and then Clausing (1982) optimized and verified the feasibility of model by the demonstration test. Based on the study above, Clausing et al. (1987) studied the influence on the convection heat transfer with different receiver cavity size obtained by the demonstration test. LeQuere et al. (1981), Koenig and Marvin (1981) proposed an experimental correlation formula on the natural convection heat transfer of solar cavity receiver. Stine and McDonald (1989), Harris and Lenz (1985) and Kaushika (1993) studied the influence on the convection heat transfer with different inclined angle and structure of receiver. Paitoonsurikarn et al. (2004) performed three-dimensional numerical simulation for the cavity receiver to study the influence on the convection heat transfer with different inclined angle and structure of receiver. Sendhil Kumar and Reddy (2007) built two-dimensional numerical simulation to obtain the natural convection heat transfer.

With regards to the radiation heat transfer in a cavity receiver, a prevailing method employed is the Monte Carlo method (MCM), which is also called ray tracing method and based on a mathematical probability model (Tan et al., 2006). The essential process to calculate radiation heat transfer with the MCM can be described as follows. The radiation heat transfer could be divided into many sub-processes, including emission, transmission, reflection and...
absorption. By fabricating the probability model of each sub-process, the radiation heat transfer in a cavity can be solved. Based on MCM, Steinfeld and Schubnell (1993) studied the influence of baffles on the property of a parabolic cavity receiver under optimal parameters. Sootha and Negi (1994) investigated the optical design of a tubular receiver and the property of solar radiation concentration using MCM. They also presented the local heat flux distribution and the maximal temperature zone of the tubular receiver surface. Spirkl et al. (1998) utilized MCM to explored the effect of angle factors is to be expected to overcome the disadvantages of the Monte Carlo method on huge amount in time and memory due to the probability statistic model used by MCM.

The actual radiation heat transfer in a hexahedral cavity receiver is a coupled process involving multiple surfaces due to its spatial structure. Therefore, referring to the interaction of multi-surfaces radiation in a large size cavity receiver, the objective is to propose a radiation heat transfer model based on the net heat method and thermal equilibrium principle in this study. By combining the finite difference method and an automatic mesh-generating technique, a set of angle factor equations of the polyhedral structure in a receiver are to be solved to obtain the heat transfer characteristics of the receiver. The method on the basis of angle factors is to be expected to overcome the disadvantages of the Monte Carlo method on huge amount in time and memory when calculating the radiation in a cavity receiver. Furthermore, by considering the convection heat transfer between the receiver inner surfaces and ambient air with the available convection correlations, a comprehensive model of heat transfer in the cavity receiver is completed. Later, regarding to the cavity receiver of the MW solar power tower plant in Beijing, the thermal efficiency of the cavity receiver is to be evaluated, and the cavity receiver structure is to be optimally designed according to the model proposed.

2. Modeling

2.1. Radiation-convection heat transfer model in a cavity receiver

Generally, the geometric prototype of a cavity receiver in a tower solar thermal plant is a hexagonal-prism cubic structure. Because all of the heated tube panels are attached at the inner surfaces of the receiver, the mutual spatial geometries of its six inner surfaces determines largely its radiation thermal performance. Actually, the cavity receiver is an artificial gray body by its non-orthogonal inner surfaces to enhance the absorptivity for the solar radiation fluxes exchanged by its any inner surface with the surrounding media. Therefore, the normal direction of the solar radiation flux to the absorption plane at solar receivers. He obtained the distribution of radiation heat flux in the receiver through the model. Shuai et al. (2008) investigated the radiation thermal performance of a cavity receiver in a dish solar power plant using MCM, taking a full consideration of the influence of baffles and receiver heated surfaces angles. Meanwhile, they proposed a model of a reverse pyriform cavity receiver on the basis of constant heat flux. Aiming at the solar reflection to be optimally designed according to the model proposed.

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