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Experimental study on thermal performance of a water/steam cavity receiver with solar simulator

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Abstract

The performance of cavity receiver plays a fatal role in light-heat conversion process in a concentrating solar power (CSP) plant. In our present work, an experimental platform is designed and built, in which a solar simulator consisting of seven mutually independent xenon lamp units is used for supplying the solar energy needed. The cold start-up and steady state performance of the cavity receiver were studied under 0.5MPa. The results show that for a certain cavity structure, temperatures on boiling panels and thus the heat loss can be affected not merely by the heat flux, other parameters can influence the temperature of absorbing surfaces, such as the heat transfer in the boiling tubes, fluid flow states and the wind effect, so the temperature distribution is highly non-uniform on boiling panels. However, the temperatures of passive surfaces depend greatly on the input solar energy, thus the heat losses of the passive surfaces will vary with the input energy. Overheat occurs if a high heat flux doesn't have a sufficient heat transfer inside boiling tubes internal. The stagnation zone does exist in the cavity and its boundary varies with a different input energy, thus the convective heat loss can be affected. The cavity receiver thermal efficiency is 72.92% under 0.5MPa, may be the reason behind this low efficiency is the strong cooling wind of the solar simulator.

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Keywords: Solar energy,central cavity receiver, start-up thermal performance, solar simulator, thermal efficiency

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1. Introduction

Environmental crisis caused by utilization of traditional fossil energy, especially in China where haze problem had drawn attention of whole society and became a burden upon the country's government, urging us to seek clean, renewable and sustainable energies as soon as possible. As one of the main sustainable energy, solar energy generation capacity had a spectacular growth during the last few years in China [1-3]. Due to a more environment friendly and a more extensive usage advantages, Concentrated Solar Power (CSP) systems for power generation maintain the research focus among all the solar energy technologies. Compared with other CSP technologies, solar power tower (SPT) system can obtain a greater solar concentrations and a higher operating temperature thus a higher system efficiency. With a higher working temperature, both the radiation and the convection heat losses will increase, so cavity receiver is a good choice and has drawn more and more scholars since the 1970s. During the last decades, thanks to the R&D Programs and development of computing science, heavy investment brought up a number of commercial demonstrating power plant [4], meanwhile lots of optical-thermal-fluid coupling model were developed. Piña-Ortiz et al. [5] built an experimentally setup, a comparison between six different turbulence models and experimental profiles was performed in a cubic cavity. Teichel et al. [6] investigated the active and passive surfaces optical properties in the cavity receiver and proposed suggestions on the selection of absorptivity and emissivity of surfaces during the design stage. Flesch et al. [7] designed an electrical heating system and analyzed the influence of wind on the convective heat losses of a cavity receiver, the results reveal shrinking of the stagnant zone might be the main reason why the losses increased. Hao et al. [8] established a setup to study the hydrodynamic characteristics of the boiling panels under a non-uniform heat flux distribution, an electrical heating method was adopted, the results found that flow distribution became significantly worse with the increase of heat flux and concentration ratio. López-Herraiz et al. [9] studied the effects of optical properties of coatings on the cavity thermal performance. Deng et al. [10] developed a radiation heat transfer mode based on the angle factor equations. Hu et al. [11] did a numerical simulation on the wind effects on the convective heat loss. Zhang et al. [12] studied the thermal performance of molten salt cavity receivers with different structures and proposed heights shall be paid more attention to enable receivers achieve a high efficiencies. Wang et al. [13] proposed a model in which Gebhart method is adopted to simulate the solar radiation in the cavity and the cavity effects were investigated. Qiu et al. [14] analyzed the time dependent optical performance of a cavity receiver. Ho [15] presented a review of new technologies to get a higher outlet temperature, newly-developing heat carrier were discussed.

From the review above, we can see that a great many of researches focused on numerical simulations of thermal performance of the cavity receiver included the heat flux distribution, radiation and convective heat losses. As for the experimental studies, an electrical heating mode has always been chosen as a heat source for the cavity receiver. The electrical heating method has weaknesses below to simulate the solar-thermal conversion: (1) the absorption and reflection of the light on tubes which is the nature of light to thermal conversion are neglected; (2) temperatures of these surfaces without cooling measures will very high and can transfer heat to boiling tubes by thermal radiation, the electrical heating method merely heat boiling tubes and ignore this thermal radiation of passive surfaces;(3) The electrical heating method heating tubes on the whole cross section of tubes which is different from the actual half cycle heating state, and this method cannot simulate the highly non-uniform heat flux distribution on the boiling panels.

In industrial concentrated solar power plant, the cavity receiver has more than one boiling panels and each panel consists of a large number of parallel tubes, the fluid flow condition in every tube is quiet complex due to a different flow resistance, and when these panels exposed to a highly non-uniform heat flux, what will happen in the tubes are difficult to predict. So in our present study, we established a water/steam cavity receiver performance testing system having a solar simulator made up of seven xenon lamp units that can supply energy having a spectrum similar to that of the sun. Cold start-up performance of a water/steam cavity receiver was studied under 0.5MPa, and the receiver efficiency was obtained at steady state.

2. Experiment platform description

The system diagram of the experiment platform is shown in Fig. 1. The deionized water at room temperature was pumped out of the feed water tank and fed into the deaerator. After being deaerated, the water was fed into the steam

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