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Experimental study of a single quartz tube solid particle air receiver

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Abstract

This article presents an experimental evaluation of a specially designed quartz tube solid particle air receiver. A new air intake tube was designed, which is conducive to realize solid particles fluidization inside a quartz tube under lower inlet air flow rate and very few particles were blown out of the receiver during operation. With the air intake tube, a single quartz tube solid particle air receiver was designed and manufactured. Concentrated solar radiation was absorbed and converted into thermal energy in an air flow by particles inside the receiver. Multi-condition experiments have been done to test the dynamic thermal performance of the receiver on a $10kW_{th}$ solar furnace system. Experimental research focuses on the effect on the particle-air bulk temperature and outlet air temperature and their temperature difference with different particle diameters, particle volume fractions and inlet air flow rates. During the experiments, the maximum outlet air temperature obtained was 598.9°C, and in some working conditions the average temperature differences between particle-air bulk and outlet air were less than 50°C, showing good convective heat transfer between particles and air. The experiments resulted in the following conclusions: (1) smaller particles may lead to lower temperature difference between particle-air bulk and outlet air due to large specific surface area, (2) larger particle volume fraction leads to lower particle-air bulk and outlet air temperature difference, however, excessive particles cause poor fluidization state and heat transfer between particles and air, and thus higher temperature difference, (3) on condition that the particles and air are evenly mixed, higher inlet air mass flow rate results in lower temperature difference between particle-air bulk and outlet air. Besides, the fluidized state inside the receiver is dependent not only on the inlet air mass flow rate but also on the particle-air bulk temperature. The accumulated operating time of the receiver exceeded 20 hours without any major failure.

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1. Introduction

Higher temperature of heat transfer fluid offer the potential to increase the solar-to-electric conversion efficiency. Solar power tower and dishes have also been proposed with air receivers that feed hot air to a steam generator. The hot air temperature range is 700°C -800°C and the absorber working temperature usually more than 1100°C. Brayton cycle systems that use gas turbine with compressed hot air to produce electricity operating at temperature exceeding 1,000°C may require volumetric air solar receivers working under high concentrated solar irradiation. Air receiver is a crucial issue for steam Rankine cycle or air Brayton cycle for plants that use air as the heat transfer fluid. Currently, the popular air receivers developed are volumetric type and tubular type, whose absorbers or tubes are heated directly by concentrated solar irradiation and kept stationary. Due to the optical characteristic of heliostats field or dish concentrator, the absorbers or tubes usually work under high, non-uniform, and unstable incoming heat flux of concentrated solar radiation. The “hot spot” damage is the most common problem of air receivers. To overcome the “hot spot” problem, the air flow rate is usually increased to enhance the heat transfer between the absorber or tube and air, which leads to the decrease of outlet air temperature. Using solid particles as absorber to get high temperature air is a promising and upcoming technology. During 1982 and 1992, the researchers of U.S. Sandia Laboratory [1-3] conducted a great deal of studies on solid particle solar receiver and obtained lots of valuable experimental data. Chen H [4] found that receiver efficiency decreased with particle diameter ranging from 200μm to 1000μm, smaller particles led to high outlet air temperature and high receiver efficiency. G. Flamant et al [5] tested the performances of packed bed and fluidized bed with silicon carbide and zirconium oxide particle as heat absorber, the results revealed that fluidized bed air receiver performed better than packed bed air receiver. Rudi Bertocchi [6] designed and fabricated a solid particle solar receiver with sub-micrometer carbon particles as heat absorber, outlet gas temperatures exceeding 2100 K were obtained with nitrogen, 1900 K with CO_2, and 2000 K with air. In 2013, a five quartz tubes solid particle air receiver was developed, tested and resulted in some conclusions [7]. During the five-tube receiver study, one problem is that because cold air was supplied to the five tubes through only one air inlet, the air flow distribution of each tube was uneven, leading to different fluidized state inside each tube and poor controllability of the receiver. Besides, the fluidized state of each tube was dependent on the particle-air bulk temperature inside each tube. Therefore, in order to reveal the effect of inlet air flow rate on the receiver performance, a single quartz tube receiver was designed and tested.

Nomenclature

dp	Particle diameter, mm
f	Input electricity frequency of fan, Hz
h	Height of particle layer inside a quartz tube, m
L	Height of a quartz tube, m
θ	Particle layer height ratio, h/L

2. Receiver design

To obtain high-temperature outlet air, three key requirements must be satisfied. Firstly, solid particles are exposed to solar radiation with long residence time. Secondly, solid particles are fluidized under low inlet air flow rate. Thirdly, solid particles and air are evenly mixed to enhance the convective heat transfer between them.

The layout of the single quartz tube solid particle air receiver is shown in Fig. 1. The receiver is composed of one quartz tube, air intake duct, solid particles, air inlet, air outlet and thermal insulation, etc. The outer diameter of the quartz tube is 40mm, thickness of 3mm and length of 500mm. The receiver uses silicon carbide particles as heat absorption materials, and air as heat transfer fluid. The air intake tube is a device that is conducive to realize solid particles fluidization inside the tube under low inlet air flow rate and very few particles were blown out of the receiver during operation. There are some holes on the air intake tube in the axial direction. One end of the air intake duct is sealed and the other is the air inlet. It should be pointed out that the air intake tube does not position along the