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Research Paper

Experimental investigate on thermal properties of a novel high temperature flat heat pipe receiver in solar power tower plant

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HIGHLIGHTS

- A novel high temperature two-phase flat heat pipe receiver applied in solar power tower plants is proposed.
- FHPR has good startup performance and isothermal property.
- Input heating flux and inclination angle has a significant effect on the performance of the FHPR.
- FHPR ensure long term safe and stable within a certain range of heating power operation.

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ABSTRACT

The high temperature two-phase flat heat pipe receiver (FHPR) is placed in solar power tower plant, which can achieve the uniform heat flux distribution and remove heat spots. This paper presents an experimental study of heat transfer performance of a FHPR. While liquid sodium (Na) shows potential for solar thermal power systems due to its wide range of operation temperatures, a simple receiver sample filled with liquid Na was developed. A series tests were performed to investigate the influences of input heating flux and inclination angle on FHPR thermal behavior. The experimental investigations were also conducted to validate the performance of fast response characteristics. The results indicated that high temperature FHPR has good startup performance and isothermal property, input heating flux and inclination angle has a significant effect on the performance of the FHPR. It also can effectively prevent thermal stress and heat spots. Based on these studies, guidelines are provided for its installation in high-temperature concentrated solar thermal central-receiver systems for power generation.

1. Introduction

With rapidly increasing energy prices and globalization, process industries seek opportunities to reduce production costs and improve energy efficiency. Among the energy-efficient technologies, Concentrating Solar Power (CSP) system is considered as one of the most attractive ways to solve the energy crisis in the future [1,2]. To accelerate the deployment of CSP technologies it is vital to improve cost competitiveness compared to other energy conversion technologies. Solar thermal power is a very promising and challenging technology for its clean and renewable energy resource [3–5]. In the solar receiver of thermal power system, the heat transfer media is heated by highly concentrated radiation to some high temperature, and then it can be used to operate kinds of heat engine and generate electricity [6,7]. Since the solar receiver is the key problem for light-heat transformation, its heat transfer performances are the research hotspot for solar energy.

Wang et al. [8] proposed an integrated simulation approach, which couples Monte Carlo ray tracing and Gebhart methods to simulate solar radiation transfer in a solar power tower system with a cavity receiver. Xu et al. [9] puts forward an innovative receiver design for high-temperature solar dish system. The novel design has both the advantages of a honeycomb configuration in enhancing heat transfer performance and uniform flux distribution. At the same time, the design is bundled using tapered tube. The structure of the receiver is simple and the cost is cheap. Luo et al. [10] proposed a novel central receiver design to improve solar tower power efficiency. It combined an external and cavity receiver for boiling and superheating sections. Most established solar tower power plants use water as the heat transfer fluids (HTF), which are mature and cost-effective configurations without extra energy storage requirements.

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Nomenclature

A	surface area [m^2]	R	thermal resistance [K/W]
c_p	specific heat at constant pressure [J/kg K]	T	temperature [K]
d	diameter [m]	T_{in}	the inlet temperature [K]
k_{eff}	equivalent conduction coefficient [W/m K]	T_{out}	the outlet temperature [K]
l_{eff}	effective length[m]	T_e	the evaporator temperature [K]
$\dot{m}$	mass flow rate [m^3/h]	T_c	the condenser temperature [K]
Q_{in}	input heat power [W]	t	time [s]
Q_u	transmitted power [W]	η	efficiency
q	thermal flux [J/m^2 s]		

Heat pipe is an excellent heat transfer component, and it has been applied to solar receiver. Because of its importance and technique complexity, heat pipe receiver is the component of advanced solar energy system which has been devoted the most since 1980s. Since then, numerous studies have been carried out. Lu et al. [11] investigated the heat absorption performances of heat receiver with spirally grooved pipe. The basic physical model of heat absorption process was proposed using the general heat transfer correlation of molten salt in spirally grooved pipe. As a conclusion spirally grooved pipe can be a very effective way for heat absorption enhancement of solar receiver, and it can also increase the operating temperature of molten salt. Zhu et al. [12] designed a new type of compound parabolic concentrator solar air collector with flat micro-heat pipe arrays. The instantaneous efficiency could reach 62%. Buttinger et al. [13] developed and investigated a new flat stationary evacuated CPC collector. They reported that heat loss reduction by using thin inert gases is as important as radiation concentration. Thermal test confirmed the theoretical results that collector efficiencies greater than 50% are possible at working temperature of 150 °C at standard conditions.

Heat pipes can achieve extremely high thermal transport capabilities utilizing a liquid-vapor phase change of the working fluid. For a high-temperature application over 450 °C (723 K), however, the working fluid must be a liquid metal. A significant number of studies can be found in the literature dealing with liquid metal heat pipes for solar receiver applications [14–18]. Generally, the flat-shaped heat pipe have lot of advantages over cylindrical one in term of heat removal capability, geometrical adaptation for variety of applications, ability to dissipate a concentrated heat source, and the production of an entirely flat isothermal surface [19]. Many flat heat pipes have been studied experimentally and reported to show good performance [20–25] and investigated the thermal performance, transient behavior and operational startup characteristics. Wang and Vafai [26] experimentally investigated the thermal performance of a flat plate heat pipe. They found that the porous wick in the evaporator section provided most of the thermal resistance and a higher temperature drop than the other layers in the flat plate heat pipe. Almsater et al. [27] investigates an approach for reducing the thermal resistance by utilizing axially finned heat pipes. Khalifa et al. [28] presents a thermal network model for evaluating heat transfer enhancement in a high-temperature latent heat storage unit incorporating finned heat pipes. The objective of this heat enhanced latent heat storage system was to improve the thermal performance of concentrating solar power plants.

Based on literature observations, a number of studies regarding the design and performance evaluation of flat heat pipe also flourished lately. A review of the related literatures indicates that the flat heat pipe is characterized by large heating area and excellent temperature uniformity, but very little attention has been paid to study flat heat pipes receiver applied on solar power tower plant. And to date there have been no studies investigating the effect on stability and fast responsibility under unsteady input power. The present study is performed to predict the thermal performances of the FHPR using water and study the effect of incline angles and input powers on the performance of FHPR. Also the thermal stability with unsteady input power was presented and discussed. It is expected that the result will provide useful information for its installation in applications.

2. Experimental setup and procedures

2.1. The Novel high temperature two-phase FHPR

The novel high temperature two-phase FHPR is a high efficiency heat transfer unit, relying on a phase transition of the working liquid to transport large amount of heat. As illustrated in Fig. 1, the structure is composed of a vapor chamber, water jackets and serrated fins, it is easily manufactured. The vapor chamber is made of Stainless steel 310 s and small amount of liquid Na filled in it. It is constructed of two flat plates with 3 mm in thickness and a frame. Its size is 530 mm × 200 mm × 12 mm with the evaporator, adiabatic and condenser section lengths are 200 mm, 130 mm, 200 mm respectively. The condenser section is composed of water jackets. One side water jacket is 200 mm in height, 200 mm in width, and 9 mm in thickness. Serrated fins brazed inside the vapor chamber and water jackets act to enhance the heat transfer performance, are 6 mm in height, 2 mm in pitch, and 0.2 mm in thickness. Fig. 2 shows the structures of these serrated fins. As shown in Fig. 3, the working principal of the novel two-phase FHPR is as follows, heat is supplied to the evaporator wall, which causes the liquid contained in the pool to evaporate. The generated vapor then moves upwards to the condenser. The heat transported is then

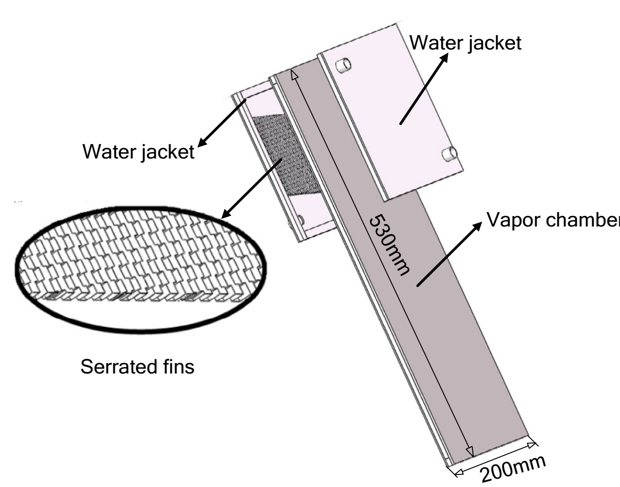

Fig. 1. The structure of solar receiver.