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Thermal performance of a novel linear cavity absorber for parabolic trough solar concentrator

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ABSTRACT

A novel linear cavity absorber for parabolic trough solar concentrator (PTC) was designed in the present study. The cavity absorber was used for conventional fabrication techniques and its thermal performance was carried out. The theoretical model of thermal efficiency for the cavity absorber has been established and verified by the experimental results. The results revealed that there was an agreement between the model and experiment. Furthermore, the temperature of the working fluid could reach 570 K, and the thermal efficiency of the cavity absorber was comparable to that of evacuated tube when the temperature of working fluid was in medium temperature. In conclusion, the thermal performance for the cavity absorber with glass cover and fins was improved.

1. Introduction

On the increasing level of severe energy crisis and the urgent need for environmental protection, the research for renewable energy has captured. Solar energy is getting much attention over the past decades with its renewable, clean and abundant characteristics [1–3]. The main utilization of solar energy can be classified into the following three aspects: photovoltaic, photo-thermal and photochemistry [4]. The operating efficiency of commercial photovoltaic system can be as much as 17%. According to the temperature range, the thermal utilization of solar energy can be classified into low, medium and high temperature. The traditional non-concentrating collector has excellent thermal performance at low temperature. Nevertheless, the non-concentrating collector is very difficult to reach high temperature with its large thermal dissipating area. Therefore, concentrating collector is usually used in the medium and high temperature with small absorbing surface and low heat loss [5].

There are three main types of linear concentrating collectors, namely PTC, linear Fresnel solar concentrator and compound parabolic solar concentrator. The thermal energy from the linear concentrating system is used for power generation, heating, cooling and desalination [6]. At present, the PTC as one of the mature technologies has been successfully operated in many countries [7]. The solar rays are collected by the concentrating mirrors of PTC and transferred to the focal line. Thereafter, the radiant energy converted into thermal energy which is then transferred to the working fluid inside the absorber by the accurate control of a solar tracking device [8]. In that process, the absorber is a carrier for converting solar energy. Consequently, its performance is important for the whole system.

The commonly used absorber is the evacuated tube in PTC. The evacuated tube has a tremendous advantage in eliminating convective thermal loss, but the high cost and leakage between glass and metal tube are its shortcomings [9]. However, the shortages of the evacuated tube can be made up by cavity absorber with operating temperatures at low and medium ranges. Many researchers have carried out lots of studies on cavity absorber. A cavity absorber with the cambered absorbing surface was proposed by Boyd et al. [10]. In order to reduce the thermal loss of the proposed cavity absorber, an insulating layer was covered on the out wall. The structure of the cavity absorber proposed by Boyd was improved [11] and the circular tubes were added to the cambered absorbing surface. The previous studies [12–15] reported that all solar rays could not be absorbed directly by the circular tubes and some solar rays were absorbed by the cambered absorbing surface. The cavity absorber with various structures was studied in [2], and the results revealed that cavity absorber with triangular absorbing surface has perfecting optical efficiency, and the average thermal efficiency of cavity absorber was more than 40% when the temperature of working fluid reached 363 K. Singh et al. [8] designed a trapezoidal cavity absorber which was suitable for heating water at 333–368 K, and the thermal efficiency of the trapezoidal cavity absorber decreased with the increasing of the concentrating ratio of the Fresnel reflecting collector.

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Nomenclature

R_{ins}	outer radius of insulating layer (m)
R_{abs}	radius of the cavity absorber (m)
d	width of the aperture of cavity (m)
w	distance from arc center to aperture (m)
Gr	Grashof's number
t	temperature (K or K)
α	coefficient of volume expansion
l	characteristic length (m)
Q	quantity of heat (W)
λ	coefficient of heat conductivity (W/mK)
Re	Reynold's number
V	flow rate (m/s)
v	kinematic viscosity (m^2/s)
Pr	Prandtl's number
Nu	Nusselt's number
S	solar radiation of cavity absorber (W/m^2)
I_b	direct solar radiation (W/m^2)
D	width of the aperture of system (m)
ρ	reflectivity of concentrating mirror
γ	interception factor
η	thermal efficiency
m	flow rate of working fluid (kg/s)
C_p	thermal capacity (J/kg K)
U	uncertainty
ξ	correction factor
U_r	relative uncertainty
r	reflectivity
τ	transmissivity
b	wetting perimeter (m)
A_c	Aperture area (m^2)

Subscripts

g	glass
i	inlet
o	outlet
f	working fluid
t	testing experiment value
rad	radiation
abs	absorber
$conv$	convection
ins	insulation
$cond$	conduction
a	ambient
1	absorbing surface
2	outer surface of cavity
3	outer surface of insulating layer
h	horizontal
v	vertical
d	downward
u	upward

In order to get a high thermal performance of cavity, a new linear cavity for parabolic trough solar concentrating system has been designed. The cavity is made by the conventional materials and fabrication techniques, and its thermal performance will be discussed in this paper. It was significant that the designed cavity absorber had a high thermal performance.

2. The cavity absorber and experimental set-up

2.1. The cavity absorber

The cavity absorber was made of aluminum alloy materials, where that aluminum alloy has fine heat conductivity, small density and high strength. The absorbing surface of the cavity absorber structure was of *V*-type. Furthermore, the back of the absorbing surface has rectangular fins, which could improve the thermal efficiency of the cavity absorber with the rectangular fins as shown in Fig. 1. The relevant parameters of the cavity absorber are showed in Table 1.

In order to reduce the irradiant heat loss from the absorbing surface of the cavity absorber, the radiation shields are set at the aperture of the cavity absorber and the glass cover is placed between the radiation shields as shown in Fig. 2 and Table 2 shows the properties of the glass cover. The glass cover is also coated with selective layer to increase the transmittance of solar radiation and minimize radiation heat loss. Due to the low emissivity of tube receiver at working temperature and the selective layer of glass cover, the radiation heat loss at working temperature (wavelength >3 μm) is very small [7].

2.2. The experimental set-up

Fig. 3 shows the schematic diagram of the experiment, the solar rays are concentrated to the cavity absorber by the reflecting mirrors under the regulation of solar tracking device. The working fluid flows circulated along with the pipe, circulating pump, the flow meter, the valve, the cavity absorber and the oil tank respectively. The working fluid was heated within the cavity absorber. Therefore, the inlet and outlet temperatures of the working fluid were measured on both sides of the cavity absorber by using two sensors (PTWD-1A with the accuracy of ±0.1 K) during the test. Meanwhile, one more PTWD-1A sensor was used to measure the ambient temperature around the parabolic trough solar concentrating system. The flow rate of the working fluid was controlled by a valve. The solar radiation was measured by pyrheliometer

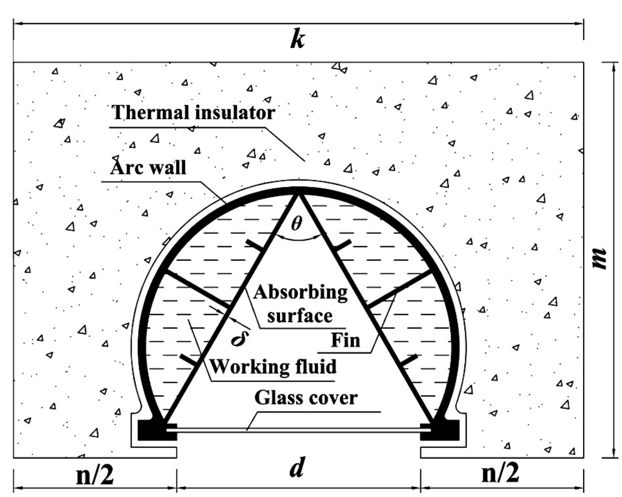

Fig. 1. The cross section of the cavity absorber.

Table 1
The geometries of the triangular cavity absorber.

Parameters	Symbol	Specification	Unit
Inscribed angle	θ	60	°
Thickness	δ	2	mm
Thermal conductivity	λ	180	W/m K