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Numerical study of a novel miniature compound parabolic concentrating photovoltaic/thermal collector with microencapsulated phase change slurry

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A B S T R A C T

The efficiencies of solar energy collectors are mainly limited by the light collecting ability and the performance of solar cells. In this work, a novel type of compound parabolic concentrating photovoltaic/thermal collector with microencapsulated phase change slurry was proposed to solve these problems. The designed solar collector was reduced to a 3–dimension physical model and numerically studied. Solar cells temperature, outlet temperature of the fluid, electrical, thermal and overall efficiency were simulated and analyzed to evaluate the dynamic performance of the hybrid photovoltaic/thermal collector. The comparison has been done between the microencapsulated phase change slurry and water as cooling fluid in the daytime. It was found that the thermal and electrical efficiency had both been improved due to the existence of the latent heat of microencapsulated phase change slurry. When the solar radiation was the lowest at 18:00, the thermal efficiency was the highest, 78.5% for microencapsulated phase change slurry and 71.9% for water, and the electrical efficiency was also the highest, 11.8% for microencapsulated phase change slurry and almost the same for water. And when the solar radiation reached highest at noon, the thermal efficiency for microencapsulated phase change slurry and water dropped to 58.6% and 55.3%, the electrical efficiency for microencapsulated phase change slurry and water dropped to 11.4% and 11.2%. The maximum thermal efficiency enhancement by using microencapsulated phase change slurry was 9.24% and the maximum electrical efficiency enhancement by using microencapsulated phase change slurry was 1.8%. Above all, the proposed compound parabolic concentrating photovoltaic/thermal collector with microencapsulated phase change slurry flow has potential for further development in solar energy application.

1. Introduction

Solar energy is a renewable, clean and abundant source of the future energy utilization. It is freely available everywhere, but its utilization with high efficiency remains both a technical and economic challenge. The low energy transformation efficiency inhibits its application. The system efficiency can be improved in both electrical and thermal aspects. The electrical efficiency can be improved by reforming the solar cells, as summarized by de la Mora et al. [1]. It can also be achieved by improving the working condition for the solar cells as presented by Calabrese et al. [2]. On the other hand, the solar energy can be collected as thermal energy. Under these circumstances, the hybrid photovoltaic/thermal (PV/T) solar collectors have become the preferred choice. It can absorb the incident photon energy and produce both thermal and electrical energy, and its electrical efficiency was found to be higher than the traditional photovoltaic solar collectors. Cai et al. [3] proposed a novel PV/T–air dual source heat pump water heater (PV/T–AHPWH) to enable it maintain efficient operation under diverse circumstances, which revealed the advantages of the PV/T collectors. Based on the hybrid PV/T system, Feng et al. [4] introduced the 3–function PV/T/D (day lighting) system, in purpose of utilizing in modern architecture with high energy efficiency. Moreover, the field test conducted by Brottier et al. [5] was carried out to give a proven methodology in designing the high–performance and reliable PV/T systems.

In order to a make more efficient use of sunlight, a concentrating PV/T module for the domestic electricity, heating and cooling application is usually put into application. The traditional mirror concentrator shaped as compound parabolic concentrator (CPC) is one of the most common non–imaging types of solar concentrators. Atheaya et al. [6] introduced an analytical expression for characteristic equation of the CPC PV/T water collector. Then by applying this analytical method, the exergy analysis for constant collection temperature mode was made to compare CPC PV/T system with the conventional types [7]. And Bahaidarah et al. [8] presented a comparative study on the effect of glazing and cooling for this type of CPC PV/T systems.

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Nomenclature

A	module surface area, m^2
c	concentration ratio
C	specific heat capacity, kJ/kg K
H	enthalpy, kJ
F	packing factor
h	convective heat transfer coefficient, W/m^2 K
I	solar radiation intensity, W/m^2
k	thermal conductivity, W/m K
$\dot{m}$	mass flow rate, kg/s
Q	heat, kJ
R	ratio
T	temperature, K
v	flow velocity, m/s

Greek symbols

α	absorption coefficient
δ	thickness, m
μ	dynamic viscosity, N s/m^2
η	efficiency
θ	half incident angle
τ	transmission coefficient

Subscripts

c	solar cell
e	electrical
en	environment
f	fluid
g	glass cover
m	melting point
o	optical
r	radiation
ref	reference value at reference conditions
s	sun
th	thermal
w	water

However, the higher concentrating ratio leads to a smaller half acceptance angle and a higher module height. Formerly, the method of truncation was used to solve this problem. But the concentration ratio is hence reduced due to the escaped reflected light. To enhance the concentration ratio, Widyolar et al. [9] designed a two–stage hybrid concentrator which reached a geometric concentration ratio of 60. Another way to solve the problem was proposed by Su et al. [10], who proposed a novel structure, namely lens–walled CPV PV module. It has a large half acceptance angle and acquiring no more solid dielectric CPC material. It comprised the transparent lens with high refractive index covering the upper surface of the CPC. The high refractive index of the lens material would increase the light incident angle, but it is harder to control the light flux distribution landed on the PV panel, which would probably seriously influence the electrical output. Li et al. [11] studied the flux distribution of this lens–wall CPC PV and aimed to regulate it. In order to gain more light, Li et al. [12] brought in an air gap between the CPC and the mirror surface to form the total internal reflection. However, the common CPV or CPV/T systems always need the tracking systems and many operational components, which are difficult to integrate with buildings. Besides, the large scale solar concentrators outside the buildings also cause the esthetic problem of buildings. Li et al. [13] proposed miniature static CPV/T systems consisting of a row of small CPCs to solve these problems.

Instead of wasting this energy, hybrid systems collect it using a heat transfer fluid (HTF). The most common HTFs used in PV/T technologies are air and water. Slimani et al. [14] conducted a comparative study between the air channel collector and conventional collector. Double–pass hybrid type was also included. And Othman et al. [15] presented a combi PV/T employing both water and air cooling medium. The water flows through the copper tube inside the air dual channel. The working performance by using these two HTFs was measured. In order to improve the heat capacity of the HTF, microencapsulated phase change slurry (MPCS) is brought out which has great heat storage potential. This type of slurry consists of carrying fluid and microencapsulated phase change materials (MPCM). The MPCM is prepared by microencapsulating a core phase change material with a shell material. The core material can be organic, inorganic, their composites or eutectic. The shell material may be organic polymer, mineral crystal or

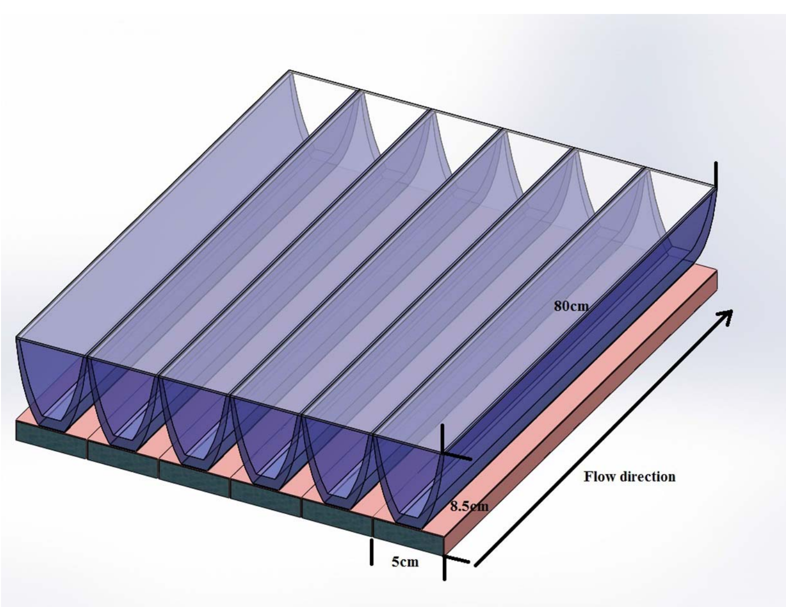

Fig. 1. Schematic diagram of the installed miniature lens–walled CPC PV/T collectors.