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Performance evaluation of a novel solar photovoltaic–thermal collector with dual channel using microencapsulated phase change slurry as cooling fluid

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ABSTRACT

In a photovoltaic–thermal solar collector, only a small percentage of the absorbed solar radiation can be converted into electricity, the rest is converted into heat. The waste heat gathering and transferring rate is the key to improve the module efficiency. In this work, a type of microencapsulated phase change slurry was employed in the photovoltaic–thermal solar collectors to improve the thermal and electrical performances. The designed photovoltaic–thermal collector was reduced to a 2–dimension physical model and numerically studied. Solar cells temperature, outlet temperature and pressure drop of the fluid, electrical, thermal and overall net efficiency were simulated and analyzed to evaluate the dynamic performance of the hybrid photovoltaic–thermal collector. Energetic efficiencies for photovoltaic–thermal model with various light concentrations versus the mass flow rate of the microencapsulated phase change slurry flow were investigated. When the concentration is 10 wt%, the photovoltaic–thermal collector obtained the highest net efficiency with the flow rate of 0.02 kg/s and the piping height of 10 mm. And it was found that the temperature variation of both fluid and PV cells employing microencapsulated phase change slurry was much smaller than water, which would improve both thermal and electrical performances. Then the optimized photovoltaic–thermal module was simulated in a daytime with the comparison of conventional water type. It was found that overall net efficiency of the photovoltaic–thermal collector with microencapsulated phase change slurry reached 80.57% at 11:00, about 1.8% higher than the conventional water type. The maximum overall net exergy efficiency was 11.4% in the morning. Above all, the proposed photovoltaic–thermal collector with microencapsulated phase change slurry flow has potential for further development in solar collector.

1. Introduction

Solar energy system plays a dominant role in the solar radiation utilization for renewable energy applications due to its low cost, efficiency and non–pollution nature. Photovoltaic (PV) device/system is the main aspect of the solar renewable energy utilization by transforming solar energy into electric energy through solar cells [1]. However, the electric efficiency of PV cells cannot be significantly improved in the recent period of time. Because of the excessive photon energy after the photon transition of the semiconducting material, the extra energy is converted into waste heat, which results in the PV module temperature rise and decreases the energy conversion efficiency [2]. In order to solve this problem, the photothermal conversion is introduced to the PV system. The redundant heat is moved away for thermal energy application, thus produces a higher overall solar energy conversion efficiency, and the solar cells temperature is better managed.

The photovoltaic/thermal (PV/T) solar system is developed to fulfill this conception. The method of moving heat waste away is the subject matter of the photothermal efficiency issue. Usually fluid flowing in serpentinepipe or flat rectangular channel is used in the cooling unit [3]. Three types of cooling fluid have been used in the past applications: air, water and refrigerant. Furthermore, dual channels with different designs have been studied to test their performance [4]. The fluid may flow either above the absorber or under it. Solid phase change materials (PCM) have also been used to increase the electrical efficiency and power output of PV panel [5].

As for the serpentine–shaped tube, a 3–D dynamical model and three steady state models that are 3–D, 2–D and 1–D were built for the simulation by Zondag et al. [6]. And Yazdanifard et al. [7] did

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Nomenclature

A	module surface area, m^2
C	specific heat capacity, kJ/kg K
E	enthalpy, kJ
F	packing factor
H	height, m
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
T	temperature, K
v	flow velocity, m/s
W	pumping power, W

Greek symbols

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

Subscripts

a	airflow
c	solar cell
e	electrical
en	environment
ex	exergy
f	fluid
g	glass cover
m	melting point
n	net
p	pump
r	radiation
ref	reference value at reference conditions
t	Tedlar
th	thermal
w	water

some parameter analyses including the effects of solar irradiation, packing factor, Reynolds number, collector length, pipes diameter and number of pipes on the system performance. The necessity of the use of upper glazing was confirmed. And the total energy efficiency in turbulent regime was found to be higher than the laminar regime. Good [8] presented an overview of the performance of the PV/T systems with liquid heat carrier and air heat carrier. The exergy efficiencies of the systems in the former works were listed to reflect the merit and demerit by using the two types of heat carrier fluid. Hu et al. [9] proposed two different heat pipes used as heat carrier tube, namely, wickless heat pipe and wire–meshed heat pipe. The thermal performances of the two cases were studied and the effect of the inclination angle was investigated.

As for the flat plate channel, Hegazy [10] compared the thermal, electrical, hydraulic and overall performances of four popular flat plate PV/T air collector designs. The fan power was also considered in the evaluation. Pierrick et al. [11] introduced a dynamic high accuracy model to simulate the heat transfer process of a solar domestic hot water system. The heat exchanger was meshed in a specific way to describe the thermal conduction. The temperature levels achieved by each cell depending on the type of heat exchanger were emphasized in the calculation. Recently, nanofluid was used in the heat carrying and optical filter for PV/T systems. There are two types of design for the nanofluid–base PV/T systems, namely separate channels and double–pass design. For both designs, the upper nanofluid acts as a liquid optical bandpass filter above the PV cells and the lower nanofluid acts as the coolant removing the waste heat. Hassani et al. [12] compared the overall electrical and thermal performance of the PV/T hybrid system. It was found the separate channel system outperformed the latter one. Later work by Hassani [13] was presented to perform the nanofluid–based PV/T hybrid systems. The results showed the nanofluid implementation on PV systems can highly enhance the high–grade exergy output and reduce the emissions of CO_2. Jing et al. [14] prepared a type of silica/water nanofluids with impressive transmittance and thermal conductivity, and used it in a concentrating PV/T system. Furthermore, Bakar et al. [15] presented a design which includes a serpentine–shaped water tube and a single pass air channel to form a bi–fluid PV/T solar collector. This system can offer both hot water and air, which adds insights to the new knowledge of optimizing the utilization of solar energy by PV/T system.

Microencapsulated phase change slurry (MPCS) is a novel type of slurry which has great potential working as heat transfer fluid (HTF). Experimental study of the natural convection heat transfer performance of this HTF has been developed in a vertical helically coiled tube by Diaconu et al. [16] and in a rectangular heat storage tank by Zhang et al. [17]. The microscopic image of the microcapsules is shown in Fig. 1 [18]. This type of slurry consists of carrying fluid and microencapsulated phase change particles. Due to the latent heat of PCM, this HTF specializes in temperature control ability. The microencapsulated phase change material (MPCM) is composed by the phase change core material and protective shell. The core material can be organic, inorganic, composites or eutectic, and the shell material can be organic polymer, mineral crystal or metallic oxide. Normally, the microcapsules dispersed in the carrying fluid results in the larger viscosity, stronger heat capacity, smaller light transmittance and other changes. Qiu used MPCS as the cooling fluid in a PV/T module [19] and presented a theoretical

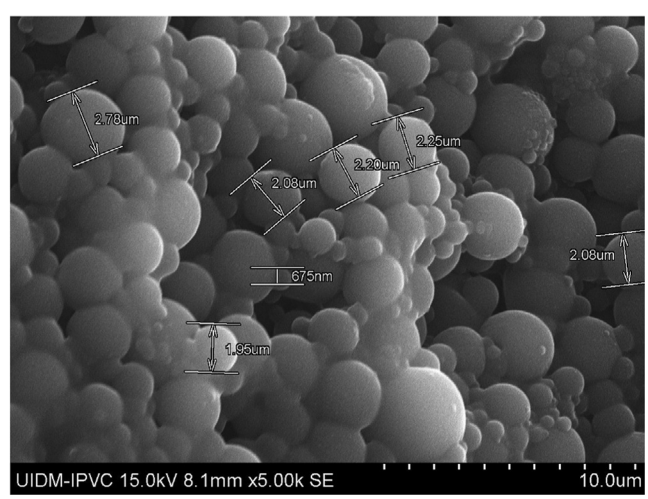

Fig. 1. The microscopic image of the microencapsulated phase change materials [18].