Renewable Energy 86 (2016) 633–642

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Investigation on a spectral splitting photovoltaic/thermal hybrid system based on polypyrrole nanofluid: Preliminary test

Wei An*, Jie Zhang, Tong Zhu, Naiping Gao

College of Mechanical Engineering, Tongji University, 200092 Shanghai, PR China

ARTICLE INFO

Article history:
Received 16 February 2015
Received in revised form
15 August 2015
Accepted 31 August 2015
Available online xxx

Keywords:
Polypyrrole
Nanofluid
PV/T
Spectral splitting

ABSTRACT

The present work developed a spectral splitting hybrid photovoltaic/thermal (PV/T) system based on polypyrrole nanofluid. This hybrid PV/T system can overcome the limitation of temperature in traditional PV/T, and achieve a high-temperature thermal output. In this system, the polypyrrole nanofluid employed in the spectral splitting filter can absorb the solar radiation that can't be efficiently utilized by PV cell unit, and convert it into medium-temperature thermal energy. The principle and methodology of the experimental system design was discussed, and the effect of particle concentration on the performance of system was investigated as well. The present work not only verifies the application potential of polypyrrole nanofluid in spectral splitting PV/T system, but also obtains some important rules on the performance. The results indicate that the temperature of nanofluid and the PV efficiency of cell unit itself increases with the particle concentration, but the thermal efficiency decreases simultaneously. The maximum overall efficiency of this hybrid PV/T system with polypyrrole nanofluid filter was 25.2%, which was 13.3% higher than that without filter. More importantly, the medium-temperature thermal energy can be harvested in such a hybrid system. Furthermore, an optimal particle concentration can probably realize a higher overall efficiency.

1. Introduction

The efficient harvesting and utilization of solar energy are one of the most promising technologies to solve energy and environmental problems due to the excessive usage of fossil fuels. Many studies on solar energy indicate that the efficiency of exclusive utilization is always limited and hybrid harvesting systems are effective approaches to promote energy efficiency. The combined photovoltaic and thermal system (PV/T) is a typical example based on this idea. Generally, it employs a fluid cooling tunnel contacted with the back surface of solar cells to harvest the thermal energy which can not be converted into electrical power [1–3]. It can not only reduce the temperature of PV cell which leads to a high PV efficiency, but it also increase the total energy efficiency. However, such a traditional PV/T system has an obvious shortcoming. The outlet temperature of the cooling fluid is only 40–50 °C since the maximum allowable temperature is constrained by the operation of PV cells. That means the collected thermal energy is mainly suitable for domestic hot water supply. It can not provide high-grade thermal energy that could be used for various thermal demands.

Recently, the development of spectral splitting technology [4–15] provides a possible way to improve the traditional PV/T. As shown in Fig. 1-a, PV/T based on nanofluid spectral splitting filter (PV/T-NSSF) employs two separated units: photothermal and photovoltaic units in light receiver. The photothermal unit, or called fluid spectral splitting filter, is filled with a selective absorption fluid which can absorb solar radiation below the band-gap energy of single-junction PV cell and convert it into medium-temperature thermal energy. If a suitable nanofluid is employed in the photothermal unit, this technology can achieve a thermal output of 150–300 °C. It breaks the limitation of temperature in the traditional PV/T, and can simultaneously provide electricity and thermal energy for more extensive applications such as solar drying [16], solar refrigeration [17], and solar desalination of sea water [18] and so on. At the same time, the fluid in spectral splitting filter is nearly transparent at the efficient waveband of the PV cell. The efficiency of PV cell will be promoted in PV/T-NSSF. Therefore, with a proper spectral match, PV/T-NSSF is believed to be a promising route for solar energy utilization.

* Corresponding author.
E-mail address: anwei@tongji.edu.cn (W. An).

http://dx.doi.org/10.1016/j.renene.2015.08.080
0960-1481/

Nomenclature

A	area of cell unit (m^2)
C	concentration ratios
C_p	specific heat capacity (MJ/m^3K)
F	AM 1.5 solar radiation intensity (W/m^2nm)
G	solar irradiance energy flux (W/m^2)
I_{mp}	current when cell unit produces the maximum power (A)
I_{sc}	short circle current of cell unit (A)
m	mass (kg)
P	power of thermal absorption unit or cell unit (W)
T_r	mean transmittance of nanofluid
ΔT	temperature rise (K)
U_{mp}	voltage when cell unit produces the maximum power (V)
U_{oc}	open circle voltage of cell unit (V)
FF	fill factor of cell unit (%)
η	efficiency (%)
τ	transmittance of nanofluid (%)
λ	wavelength (nm)

Subscript

nano	nanofluid
water	pure water
pv	photovaltaic
th	thermal

Superscript

unit	cell unit itself or photothermal unit itself
*	normalized value
-	average value

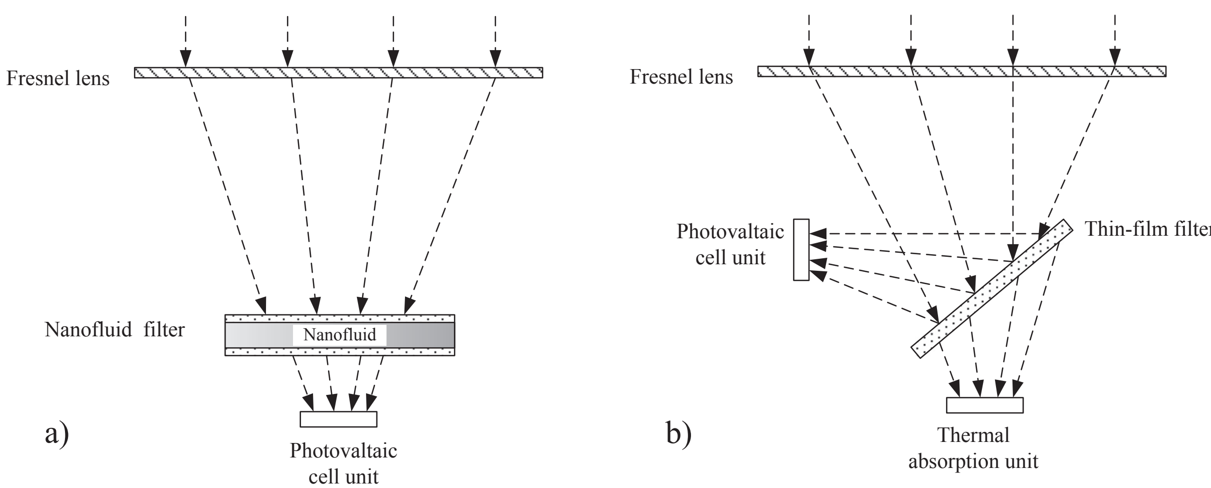

Fig. 1. The sketch of spectral splitting PV/T system: a) fluid based filter; b) thin-film based filter.

As shown in Fig. 1, the spectral splitting technology can generally be realized by two methods: liquid based absorption/transmission method (Fig. 1-a) and film based reflection/transmission method (Fig. 1-b). Compared with the latter, the former one has some specific advantages. Firstly, heat absorption and transfer in liquid based spectral splitting method are more efficient than those on solid surfaces because absorption of solar irradiation becomes a volumetric process. The radiation below the band-gap energy of cell can be directly and efficiently converted into heat. Moreover, it can achieve flexible allocations of heat and electricity for different applications through adjusting the concentration of nanoparticles. In addition, because the nanofluid is always isolated in tubes, a conventional cleaning process doesn't affect the performance of filter. Therefore, when the performance of filter is influenced by dust pasted onto the outer surface of filter, the cleaning of fluid-based filter is much easier than the film-based filter.

Powell [6] proposed the liquid-based spectral splitting method in 1981. Sabry et al. [7] developed a model to investigate the characteristics of ideal liquid filter for operation with Si cell. Recently, Otanicar et al. [8–10] proposed a more detailed method to simulate PV/T-NSSF. The effects of concentration ratios, band-gap energy, and flow of nanofluid on system performance were investigated extensively in their works. Moreover, Zhao et al. [11] proposed a model to investigate the effect of optical constant of nanoparticles on system performance. Crisostomo et al. [12] performed an optimization analysis for the waveband of liquid-based spectral splitting method. Their work is important for the selection of nanofluid.

As pointed out by Taylor [4], the biggest challenge in PV/T-NSSF is to obtain a proper nanofluid with reliable optical and thermal properties. The ideal fluid should have a high transmittance for the waveband at which PV cell can efficiently work, and simultaneously have an intensive absorption for other wavebands of solar radiation. For efficiently absorbing and conveying thermal energy, they should have a high specific heat capacity and conductive coefficient as well. More importantly, these optical and thermal properties must be stable in a high-temperature environment. In addition, they should also be non-toxic, environment-friendly, and low-cost. Chendo et al. [13,14] studied the spectral properties of several liquids, as well as their thermal stability at 50 °C and 200 °C. They found the cobalt sulfate or copper nitrate in solution, or some specific organic-based high-temperature oils could be used as liquid filter when Si cells were employed as photovoltaic unit. Otanicar [19] developed a method to determine the extinction index of liquids. The optical properties of four liquids (water, ethylene glycol, propylene glycol, and Therminol oil) commonly used in solar thermal energy applications were investigated. Recently, Looser [20] and Vivar [21] attempted to find some more suitable fluids instead of water to achieve a thermal energy with medium temperature (150°C-300 °C) under common pressure. They