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PVT type of the two-phase loop mini tube thermosyphon solar water heater

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ABSTRACT

In this paper, the performance study is performed in order to verify the new design of the photovoltaic (PV) panel combined with type of the wickless heat pipe solar water heater. In this enhanced design, each wickless heat pipe is assumed in the shape of the loop mini tube comprised of the flow boiling process inside it. Without considering the PV panel, this design was reported in our prior published work (Ziapour et al., 2016). Here, the performance of the proposed passive PVT solar collector is numerically performed using EES software. The solar cell packing factor (i.e. fraction of the absorber plate area which is covered by the solar cells) is important parameter for designing a PVT system. The simulation results show that the thermal efficiency of the passive PVT solar system increases with increase of the solar cells packing factor. Through the simulation results it is found that the optimal numbers of the wickless heat pipes may be five loops. By selecting the five loops, the maximum value of the tank water temperature is obtained near to 72 °C in the evening. Also the maximum values of η_{th} and η_{pv} are found as 70% and 80% at noon time, respectively.

1. Introduction

Because of the increased energy demand in the recent years, the current energy resources would not meet the market requirements. This means that the received renewable energy must be consumed with the highest efficiency. Therefore, the innovative research must be carried out by investigators to tackle this energy problem [2].

The solar cells were widely used to generate electricity [3,4]. Overheating of the photovoltaic (PV) cells due to excessive solar radiation in a hot day is resulted to reduce the efficiency of them dramatically [5]. For example, following Dubey et al. [6] and Rodrigues et al. [7], solar cells maximum power output (P) decreases as mean temperature of solar cells increases, as shown in Fig. 1. This means that heating of the PV modules affects the output of the panels.

Different techniques have been proposed to cool the solar cells surfaces. Direct spraying of the cold water on the PV panels is one of these methods. For example, Moharram et al. tried to minimize the water amount and the electrical energy required for the solar cells cooling in Egypt [8]. They found that the PV modules can be reached the highest efficiency if panels cooling starts at the maximum allowable temperature (i.e. 45 °C). The maximum allowable temperature (MAT) is a compromise temperature between the output energy from the PV panels and the energy needed for cooling. The net energy output from the PV panel as a function of the MAT was depicted in their works. It was resulted that as the MAT value increases, the rate of water evaporation during the cooling operation increases, and thus, more water consumption is needed. Therefore, it could be concluded that selecting the MAT to be 45 °C is the optimum value to cool the solar PV panels with the least amount of water and energy usage. However, this method may be useful for the hot and dusty days, but the mass flow rate is not adequate for thermal consumptions, because of need to stay transparency of the collector covers to transfer the solar radiation beams.

Integrating both the PV panels to generation the electricity and the produced heat energy for thermal usage has been leaded to an efficient technology as the photovoltaic-thermal (PVT) system. Most researches on the PVT systems were the hybrid systems that use a pump to turn the working fluid (water or air) within the collector [9–16].

Recently, a new concept of PVT system has been proposed as a passive PVT system by Ziapour et al. [17,18]. The passive photovoltaic-thermal system means the combination of the photovoltaic (PV) cells with an integrated collector-storage solar water heater (ICSSWH) to generation heat and electricity without any

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Nomenclature

A_c	collector area, m^2
A_p	absorber plate without solar cell area, m^2
A_{sc}	solar cell area, m^2
d_r	riser diameter, m
F	standard fin efficiency for straight fins with rectangular profile
$I(t)$	total solar intensity radiation on the collector, W/m^2
K_p	conductivity of the aluminum absorber plate, W/m K
K_{sc}	thermal conductivity of solar cell, W/m K
M_f	water mass inside the storage tank, kg
N	numbers of the loop tubes
$q_{on-plate}$	useful energy receive to a absorber plate, W
q_u	useful energy entered to a riser, W
T_{amb}	ambient temperature, K
T_f	tank water temperature, K
T_p	absorber plate mean temperature, K
T_{sc}	solar cell temperature, K
U_L	sum of the heat losses from the outer cover glass and the collector box to ambient, W/m^2
U_T	an over all heat transfer coefficient from solar cell to absorber plate, W/m^2

Greek symbols

α_{sc}	solar cell absorbance
α_p	absorber plate absorbance
β	tilt angle of the solar water heater, °
β_r	temperature coefficient of solar cell efficiency, $1/k$
β_{sc}	solar cell packing factor
δ_{sc}	solar cell thickness, m
δ_{air}	distance between solar cell and cover glass
δ_p	absorber plate thickness (here, aluminum with $\delta_p = 0.002$ m), m
ε	surface roughness of the riser tube, m
τ_g	transmittance of the cover glass
η_r	efficiency at standard test condition
η_{th}	temperature dependent thermal overall efficiency
η_{sc}	temperature dependent electrical overall efficiency
η_{pv}	total efficiency of PVT system
η_{sci}	temperature dependent electrical instantaneous efficiency of solar cell

electricity consumption devices within it such as the pump that was used in a hybrid PVT system.

The two-phase closed thermosyphan (TPCT) or wickless heat pipe is a single tube or double tubes (loop type) heat exchanger that has been used in the solar water heating applications [1,19–21]. Since these collectors do not use any electricity when they collect thermal energy, thus they act as a passive thermal system. Ziapour et al. [1] simulated an enhanced solar collector consisting of the wickless heat pipes. Each wickless heat pipe is assumed in the shape of the loop mini tube comprised of the flow boiling process inside it. They showed that, in the cases of the one and the four mini loops, the collectors' thermal efficiencies are 11% and 60% respectively.

In this paper, the performance study is performed in order to assess the new design of the photovoltaic (PV) panel combined with type of the wickless heat pipe solar water heater. Without considering the PV panel, this design was reported in our prior published work [1]. Here, the performance of the proposed passive PVT solar collector is numerically performed using EES software [22]. The proposed collector system was not found in pervious literature and there is not any similar design to it.

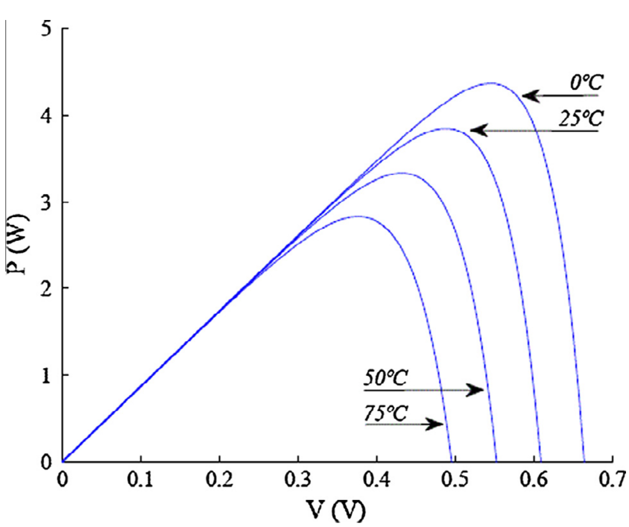

Fig. 1. P-V characteristics of the solar cell for different temperatures of the module, adapted from [7].

2. Characteristics of the proposed PVT solar collector system

Fig. 2 schematically shows the cross section of the proposed passive PVT solar collector. The system consists of separate loops of TPCT, two cover glazing, solar cells, absorber plate, insulation box and an energy storage tank. Each loops is comprised of the evaporator section (i.e. riser) on the absorber plate, condenser within the water storage tank and the downcomer back of the absorber inside the insulation box. Each loop of TPCT is filled with percentage of water as a working fluid (i.e. filling ratio is selected as 50% based on our prior work [1]). Due to the flow boiling process inside the riser, the generated vapor within it, leaves the riser space quickly; and then, the liquid inside the down comer fills the riser evacuated space.

Without solar cells, the processes formulations were completely described in Ref. [1]. By considering solar cells on the absorber plate, the following new energy balance on the solar cells is obtained as:

$$\tau_g\alpha_{sc}\beta_{sc}A_cI(t) = U_L\beta_{sc}A_c(T_{sc} - T_{amb}) + U_T\beta_{sc}A_c(T_{sc} - T_p) + \eta_{sc}\tau_g\alpha_{sc}\beta_{sc}A_cI(t) \quad (1)$$

Also, the new energy balance on the absorber plate is obtained as:

$$q_{on\ plate} = U_T\beta_{sc}A_c(T_{sc} - T_p) + \tau_g\alpha_pI(t)A_c(1 - \beta_{sc}) - U_LA_c(1 - \beta_{sc})(T_p - T_{amb}) \quad (2)$$

Therefore, the useful energy (q_u) entered to a riser is obtained as follows:

$$q_u = L_r((W - d_r)F + d_r)(q_{on\ plate}/A_c) \quad (3)$$

where F is the standard fin efficiency for straight fins with rectangular profile as follows [23]:

$$F = \frac{\tanh[m(W - d_r)/2]}{m(W - d_r)/2} \quad (4)$$

The other equations and assumptions are same as our prior works (see Eqs. (2)–(20) in Refs. [1,24,25]). In this work, it is assumed that there is not any hot water consumptions from the storage tank.