COMBINED UNCOVERED SHEET-AND-TUBE PVT-COLLECTOR SYSTEM WITH BUILT-IN STORAGE WATER HEATER

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ABSTRACT

This work describes the design and investigation of a simple combined uncovered sheet-and-tube photo-voltaic-thermal (PVT) collector system; consisting of a support, standard PV module, sheet-and-tube water collector and storage tank-heater. The PVT-collector system could work in the fixed and tracking modes of operation. During investigations in natural conditions, solar irradiance, voltage and current of PV module, ambient temperature and water temperature in storage tank were measured. Average thermal and electrical powers of the PVT-collector system at the tracking mode of operation observed were 39W and 21W, with efficiencies of 15% and 8% respectively at the input power of 260W. The maximum temperature of the water obtained was 42^{o}C.

Keywords: Combined system, Module, Collector, Storage water-heater

1. INTRODUCTION

Utilization of solar energy, which is environment-friendly, is very important for the sustainable development. As is known that one of the limiting factors of solar modules and collectors applications in especially urban area is the availability of the required sufficient land [1,2], therefore, during the last years, combined photo-voltaic-thermal collectors' designs were implemented and investigated in practice [3-12]. The main advantage of the PVT-collector system observed is to produce more electrical and thermal energy in comparison to the conventional PV modules and collectors that partially cover the same area. In addition, in comparison to separate thermal and PV system, the PVT-collectors provides architectural uniformity, reduce installation cost [13]. Basically four groups of water type PVT-collectors namely: sheet-and-tube PVT-collectors, channel PVT-collectors, free flow PVT-collectors and two-absorber PVT-collectors were evaluated and optical and thermal efficiencies of the PVT-collectors were calculated [13]. Except of the uncovered PVT-collector all discussed designs with additional glass sheet bring more reflection losses and less electrical efficiency of the system. It is also concluded in [13] that the uncovered PVT-collector for low temperature applications is most promising design. Table 1 shows transmission-absorption factors for the various design concepts (AM 1.5 spectrum) of sheet-and-tube PVT-collectors. τ_{α}, $\tau_{\alpha w}$ and τ_{pv} are transmission-absorption coefficients of PVT-collector, water and PV-module respectively [13].

Table 1: Transmission-absorption factors for the various design concepts (AM 1.5 spectrum) of sheet-and-tube PVT-collectors.

Design concept	τ_{α}	$\tau_{\alpha w}$	τ_{pv}
Uncovered sheet-and-tube PVT-collector	0.78	-	1.00
One-cover sheet-and-tube PVT-collector	0.74	-	0.92
Two-cover sheet-and-tube PVT-collector	0.71	-	0.84

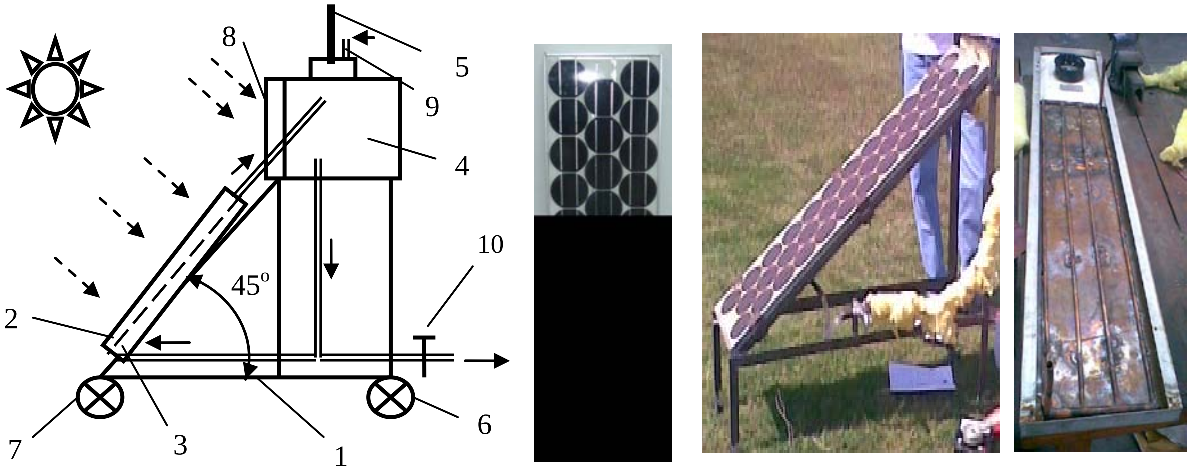
Maximum τ_{pv} is observed for the uncovered PVT-collector showing potentially highest output electric energy in comparison to PVT-collectors with one-cover and two-covers. On the other hand uncovered PVT-collector shows lower thermal efficiency compared to the covered by glass sheet PVT-collectors. So it would be reasonable to design the uncovered PVT-collector system where at high electrical efficiency the thermal efficiency would be improved. Therefore in this paper we present the design of uncovered PVT-collector system where unlike to [13] the built-in storage water heater is installed.

2. EXPERIMENTAL PROCEDURE

Fig.1a shows the design of a PVT-collector system consisting of a metallic support (1), standard PV module (2), sheet-and-tube water collector (3), and storage tank-heater (4). The water temperature in the metallic storage tank-heater was measured by thermometer (5). Wheels (6 and 7) allowed changing position of the PVT collector manually at the tracking mode of operation. In the front and two sides of the right-angle prism tank (4) the glazing was made (8) with air gap of 1cm and the surface of the tank from outside was blackened for additional heating of water by solar radiation. The bottom, back side and the top of the tank was covered by glass-wool and aluminum foil. The volume of water tank was 20 liters. Connecting PVT-collector and the tank pipes were insulated by glass-wool and aluminum foil. The cold water was filled in the system through inlet (9), the tap (10) served to release the hot water.

The dimensions of the PV module were 1.22x0.305m with a total area of 0.37m^2. PV module with crystalline silicon cells that was used in the PVT-collector system, inclination arrangement and absorbing plate is shown in Fig. 1b-d. The sheet-and-tube water collector's design mainly was similar to the described in [14]. Fig. 2 shows the design of the collector. On copper sheet of size of

0.86x0.25m four parallel copper tubes were fixed by welding. The copper was selected due to high thermal conductivity (385W/m°C) as compared to aluminum (211W/m°C) and steel (54W/m°C). The collector was insulated by glass-wool, covered by aluminum foil and plywood and fixed under PV module. Interfaces of PV module's back and collector's sheet were in good thermal contact as collector was squeezed to the back of the module. Table 2 shows geometrical parameters of the collectors: W is distance between of the centers of neighboring tubes, D is external diameter of the tube, δ is thickness of the metallic absorbing plate. Internal diameter of the tubes used in the present work was 0.006m.



(a) (b) (c) (d)

Fig. 1: (a) Design of PVT collector system, (b) PV Module, (c) Inclination setup, (d) Absorbing plate

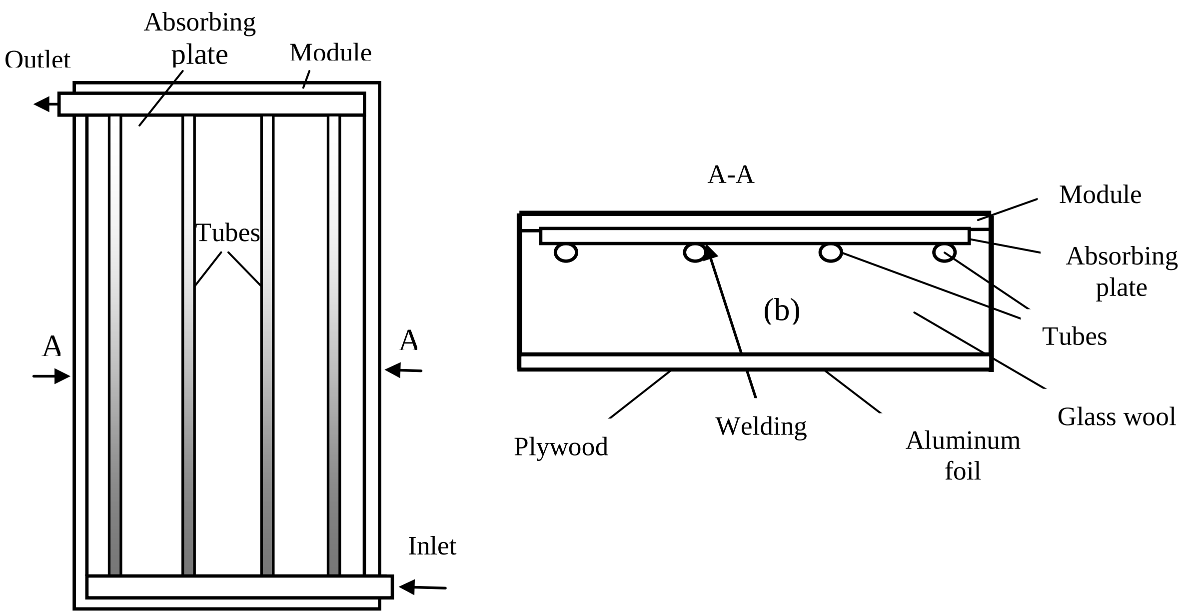


Fig. 2: Design of PVT Collector

Table 2: Geometrical parameters of the sheet-and-tube water collectors

Reference	W (m)	D (m)	δ (m)
[1]	0.200	0.020	0.003
[14]	0.125	0.008	0.035
[14]	0.100	0.008	0.045
Present work	0.060	0.008	0.003

The latitude (φ) of the place where the PVT-collector was investigated was 34 degree. Therefore an inclination angle (β) of the PVT-collector to the horizontal plane used was 45 degree (usually $\beta = \varphi + 11$degree, φ and $\varphi - 11$ degree in winter, spring/autumn and summer respectively) as the experiments were conducted from February to April 2009 at GIK Institute during 7-9 hrs. The storage tank-heater played double role i.e. for storage of hot water and for water heating. The PVT-collector system could work in the fixed and tracking modes of operation. During investigations of PVT-collector in natural conditions, solar irradiance, voltage and current of PV module, ambient temperature and water temperature in storage tank were measured.

3. RESULTS AND DISCUSSIONS

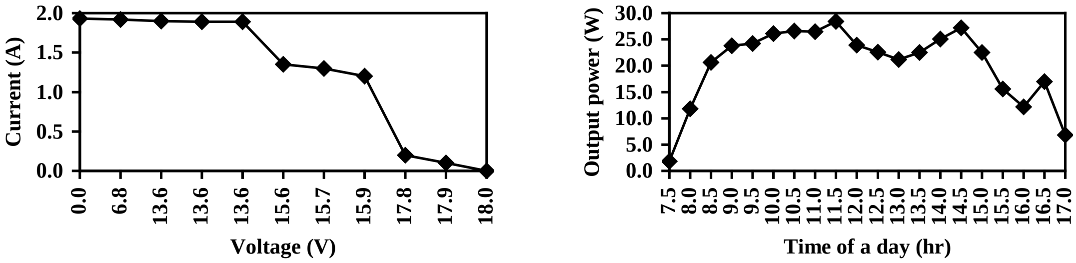
Fig. 3a shows I-V characteristics of the module at average irradiance of 878 W/m^2 and inclination angle of 45^o. The fill factor (FF) of the modules was 0.75. Fig. 3b shows the output electric power measured during one of the cloudy day for one PV module. The output electric power (P_{el}) was calculated as per [2]:

$$P_{el} = I_{sc}\, V_{oc}\, FF \qquad (1)$$

where I_{sc} and V_{oc} are short circuit current and open-circuit voltage respectively. The average efficiency (η_{el}) of the conversion of solar energy into electric power was calculated as per [13]:

$$\eta_{el} = P_{el} / GA \qquad (2)$$

where G is irradiance in W/m^2, A is area of the module. Efficiency (η_{el}) of 8% was calculated with average solar input power of 260W.



(a) (b)

Fig. 3: (a) I-V characteristics of the module at irradiance of 878W/m^2 and inclination angle of 45^o, (b) Electric output power Vs Day time for the PVT-collector system for a variable cloudy day.

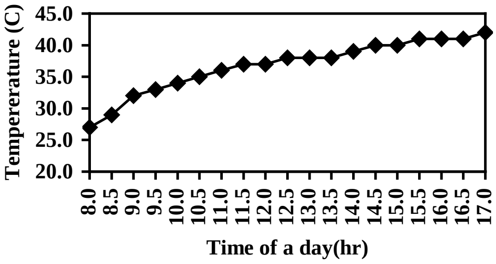


Fig. 4: The temperature of water in the tank Vs day time for a variable cloudy day.

Fig. 4 shows the temperature of water (T_w) in the tank versus day time (t) relationship for the variable cloudy day. It is seen that the T_w increased from 26^{o}C to 42^{o}C. Average ambient temperature (T_a) observed is 26^{o}C.

The collector-tank-pipes loop is considered as a thermosyphon system where the water flow takes place due to the differences of the density of the hot and cold water [1]. At the same time, experimentally water temperature in the tank was measured where in the first approximation it was assumed that the water is in the static condition. Therefore thermal output power (P_{Th}) for the case of static mass can be calculated as [1]:

$$P_{Th} = m\, c\, (d\, T_w / d\, t) \quad (3)$$

where m is a mass of water, c is specific heat capacity. By evaluation of the average dT_w/dt from Fig. 4, P_{Th} was calculated and finally the efficiency of solar energy was converted into the thermal power as:

$$\eta_{th} = P_{Th} / GA \quad (4)$$

η_{th} of 15% was calculated and may be considered the minimum as the water was not taken from tank during a day i.e. the total mass of water was constant during a day. If the tank's water is used several times a day, definitely the efficiency will increase. In the case of fixed mode of operation, without tracking, the experiments were conducted in variable cloudy day during 6 hrs, hence; it was observed that at the input power of 290W the maximum temperature of water was almost 35^{o}C at the average ambient temperature of 28^{o}C. The efficiencies of solar energy conversion into electric and thermal powers calculated were 8% and 15% respectively. Different duration of daily experiments was due to the variable clouds in February to April, 2009. At the same duration of experimental days and clear sky the efficiency of the tracking system is approximately 30% more than the fixed system [15].

In [13] annual thermal (24%) and electrical (7.6%) efficiencies were calculated for the case of uncovered sheet-and-tube PVT-collector system. The electrical efficiency is approximately the same as obtained in the present study, but the thermal efficiency is higher. The reasons of this is in the intensity of radiations, ambient temperature, construction of collector etc., and mainly maybe due to the approaches that were used for the calculations of the thermal power and accordingly the efficiency. In [13] the thermal power was calculated by:

$$P_{Th} = c(T_2\text{-}T_1)\ dm/dt \qquad (5)$$

where *dm/dt* is mass flow through the collector in a unit of time and T_1 and T_2 are the temperatures of water in the inlet and outlet of the collector. Table 3 shows the efficiencies for the PVT-collectors design concepts: annual average efficiencies for the systems described in [13] and average efficiency for the February-April 2009 for the designed PVT-collectors presented in this study.

Table 3: Average efficiencies for the PVT-collectors design concepts [13]

System	Ref.	Thermal Efficiency	Electrical Efficiency
PV	[13]	-	7.2%
Sheet and tube PVT-collector uncovered	[13]	24%	7.6%
Sheet and tube PVT-collector 1 cover	[13]	35%	6.6%
Sheet and tube PVT-collector 2 covers	[13]	38%	5.8%
Present work	-	15%	8.0%

4. CONCLUSIONS

The uncovered sheet-and-tube PVT-collector system worked successfully in both the fixed and tracking modes of operation. During investigations of PVT-collector in natural conditions, solar irradiance, voltage and current of PV module, ambient temperature and water temperature in storage tank were measured. Average thermal and electrical powers of the PVT-collector system at the tracking mode of operation observed were 39W and 21W, with efficiencies of 15% and 8% respectively at the input power of 260W. The maximum temperature of the water obtained was 42^{o}C. The system was observed efficient for low-temperature applications. The PVT-collector system may be used as a prototype for design of PVT-collector system for domestic application, teaching aid and for demonstration purposes. The output power of the PVT-collector system can be increased easily by increase of the number of PVT-collector units.

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