PERFORMANCE OF THE PVT SOLAR COLLECTOR OPERATED WITH WATER – AL_2O_3 NANOFLUID

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ABSTRACT

An experimental investigation of the hybrid module photovoltaic panel -solar collector (PVT) cooled by water-Al_2O_3 nanofluids has been conducted. The weight fractions of the nanoparticles were 1% and 3%. Thermal efficiency, power efficiency and overall efficiency have been determined for artificial source of light and sunlight. No noticeable effect of the nanoparticle concentration on the overall efficiency of the PVT module has been recorded while using water-Al_2O_3 nanofluids as a cooling medium. Moreover the reduction of the electrical power generated with increasing temperature of the module has been recorded.

INTRODUCTION

The present commercial photovoltaic cells (PV) convert solar energy into electricity with a relatively low efficiency, less than 20%. So, about 80% of the solar energy is dissipated to the surroundings again during electrical energy conversion. Furthermore the output electrical power of a PV system decreases due to the increase of PV module temperature. The increased temperature can also cause a permanent structural damage of the PV panel if the thermal stress remains for a prolonged period. Therefore, interesting alternative to PV modules is hybrid photovoltaic panel-solar collector systems (PVT), where solar collector is used to cool the surface temperature of the photovoltaic panel. Thus hybrid photovoltaic/thermal (PVT) collectors are devices that simultaneously convert solar energy into electricity and heat increasing the total energy output of the system. Research on improving the efficiency of photothermal conversion showed that the use of nanofluids as coolants in solar systems can improve the thermal efficiency of these devices (Cieśliński J.T. et al., 2016).

A computer model to investigate the effects of the use of a water-based nanofluid on the electrical and thermal efficiency of a PVT system was presented in (Xu Z. and Kleinstreuer C., 2014). Specifically, a new thermal conductivity model of nanofluids was employed to predict the enhanced heat transfer. Furthermore, the conversion efficiencies and economic aspects of the systems using silicon solar cells and multi- junction solar cells have been evaluated and compared to provide guidance for selecting suitable solar-cell types. According to the simulations the overall efficiency of PVT collectors could reach 70% with electrical and thermal contributions amounting to 11% and 59%, respectively. The effects of using silica (SiO_2)/water nanofluids as coolants on the thermal and electrical efficiencies of the PVT system were studied in (Sardarabadi M. et al., 2014). The nanoparticle concentration was 1% and 3% by weight. It was established that the overall efficiency in the case of water-silica nanofluid of 1% was increased about 3,6% compared to the case with pure water. When using the silica/water nanofluid of 3%, the increase was nearly 7,9%. The thermal efficiency of the PVT collector for the two cases of 1% and 3% of silica/water nanofluids was increased by 7,6% and 12,8%, respectively. In the paper (Gangadevi R. et al., 2013) application of water-Al_2O_3 (0,5%vol.) nanofluids to cool the PVT module was investigated. The results show that the electrical and thermal efficiency of hybrid solar system increases considerably by using the nanofluid as a working fluid. The effects of ferrofluids application as a coolant on the overall efficiency of a PVT was studied in (Ghadiri M. et al., 2015). The fluids considered in the experiment were distilled water and a ferrofluid (water-Fe_3O_4) with 1% and 3% nanoparticle concentrations by weight. The experiments were performed in indoor conditions under two constant ligth radiations (1100 W/m^2 and 600 W/m^2) using a solar simulator. The ferrofluids were placed under constant and alternating magnetic fields in the cooling section in order to investigate the effect of both types of magnetic fields on the overall efficiency of a PVT system. The results show that by using a 3% ferrofluid, the overall efficiency of the system improved by 45% and when an alternating magnetic field with 50 Hz frequency was applied, the overall efficiency increased to about 50% compared to that of the distilled water. Various types of liquid based PVT collectors are presented in (Daghigh R. et al., 2011).

This paper presents the experimental results of the performance of a commercial hybrid module photovoltaic panel-flat plate solar collector with water-Al_2O_3 nanofluid as a working fluid. The weight fractions of nanoparticles were 1% and 3%. Thermal efficiency, power efficiency and overall efficiency have been determined for artificial source of light and sunlight.

EXPERIMENTAL SETUP

The schematic diagram of the experimental rig is shown in Fig. 1. The hybrid solar collector with total area of 1006x2007 mm and absorption area of 1,86 m^2 was positioned at an angle 25° to the direction of the light beam. As a light source a set of 15 halogen lamps FL500 produced by Ansmann and sunlight was used. The incident radiation was measured by using a pyranometer CM6B produced by KIPP and ZONEN. Nanofluid was circulated in the loop by use of a pump. The inlet temperature of the working fluids was established by a thermostat. The inlet and outlet temperatures of the working fluids were measured by using K-type thermocouples. Also, one K thermocouple was used to measure the ambient air temperature. Flow rate of the working fluid was controlled by control valve and was measured by flowmeter MAGFLO Mag 6000. The measurement of the surface temperature of the photovoltaic panel was carried out using a portable infrared thermometer Fluke 63. The tests were carried out with available on the commercial market device E-PVT 2.0. The module shown in Fig. 2 is a photovoltaic panel and is made based on polycrystalline silicon cells, and a flat liquid collector integrated with the back of the photovoltaic module capable of receiving heat.

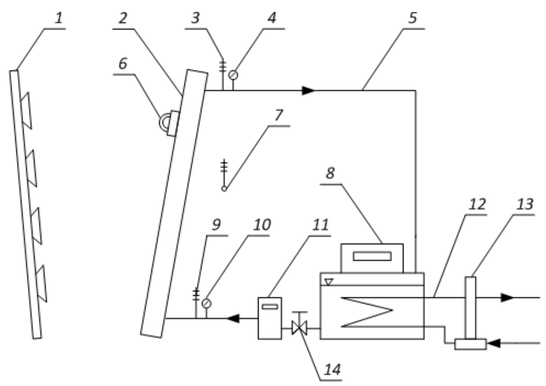

Fig. 1. Scheme of the test rig: 1 – light source, 2 – solar collector, 3,7,9 – thermocouple, 4,10 – pressure sensor, 5 – fluid loop, 6 – pyranometer, 8 – thermostat, 11 – flowmeter, 12 – coolant loop, 13 – rotameter, 14 – flow control valve

Fig. 2. Hybrid solar cell Ensol E-PVT 2.0

Electrical energy generated by the PV panel was dissipated in a specially designed electrical system.
In order to determine the current-voltage characteristics of the photovoltaic module three adjustable resistors and digital multimeters were used.

In the present study alumina (Al_2O_3) was used as nanoparticles while distilled and deionized water was applied as a base fluid. Alumina nanoparticles, of spherical form had the diameter ranging from 5 nm to 250 nm; their mean diameter was estimated to be 47 nm according to the manufacturer (Sigma-Aldrich Co.). Dispersants were not used to stabilize the suspension. Ultrasonic vibration was used for 30-60 minutes in order to stabilize the dispersion of the nanoparticles. Additionally high speed rotor-stator homogenizer was used to prepare the nanofluids. Nanoparticles were tested at the concentration of 1% and 3% by weight. The pH of the tested nanofluids was about 7.

DATA REDUCTION

The actual useful heat extracted from the solar collector was calculated as:

$$\dot{Q}_u = \dot{m} c_{p,nf} \left(T_{out} - T_{in} \right) = \dot{m} c_{p,nf} \Delta T \quad (1)$$

The instantaneous efficiency of a solar collector, operating under steady-state conditions, is defined as the ratio of the actual useful power extracted to the solar energy absorbed by the collector:

$$\eta_Q = \frac{\dot{Q}_u}{A_c G} \quad (2)$$

The instantaneous efficiency is generally presented as a function of the reduced temperature:

$$T_m^* = \frac{T_m - T_a}{G} \quad (3)$$

where the mean temperature of the fluid reads:

$$T_m = T_{in} + \frac{\Delta T}{2} \quad (4)$$

The current is determined by the equation:

$$I = \frac{U}{R} \quad (5)$$

The electrical efficiency of the photovoltaic panel was determined by the formula:

$$\eta_{pv} = \frac{P}{G \cdot A_{pv}} \quad (6)$$

where the electrical power generated by the cell is equal to:

$$P = U \cdot I \quad (7)$$

Total efficiency of the hybrid module is determined by the relationship:

$$\eta = \eta_Q + r \cdot \eta_{pv} \quad (8)$$

where the parameter r is defined by the equation:

$$r = \frac{A_{pv}}{A_c} \quad (9)$$

RESULTS

Figure 3 shows comparison of the present experimental results with manufacturer's data obtained for sunlight. The solid lines represent the manufacturer's data for three wind speeds (0,5 to 3 m/s). According to the manufacturer’s data wind speed increase results in distinct thermal power decrease. Present data - like manufacture’s data, indicate a strong relationship between thermal power and mean collector temperature difference. For lower values of the mean collector temperature difference application of pure water and both nanofluids result in higher thermal power compared to the data provided by the manufacturer. However for higher values of mean collector temperature difference advantage of nanofluid application diminishes.

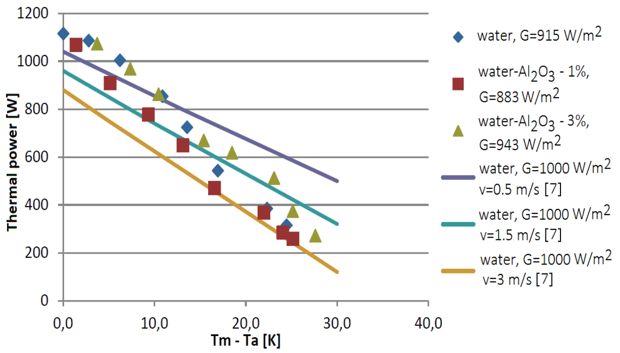

Figure 3. Thermal power versus mean collector temperature difference for various cooling liquids in relation to the data the manufacturer’s data (Ensol)

Figure 4 shows the thermal efficiency of the tested PVT versus reduced temperature in case of sunlight application for various cooling fluids, i.e. for pure water and nanofluids with nanoparticle concentration of 1% and 3%. It was noted that for nearly the same irradiance the use of water-Al_2O_3 nanofluid with nanoparticle concentration of 1% results in lower thermal efficiency compared to distilled water and no change of the thermal efficiency was recorded for water-Al_2O_3 nanofluid with nanoparticle concentration of 3% compared to distilled water.

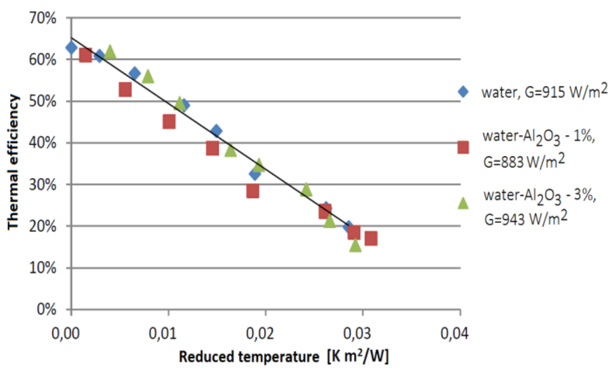

Fig. 4. Thermal efficiency versus reduced temperature for various cooling fluids

Figure 5 shows the current-voltage and corresponding power-voltage (Fig. 6) characteristics of the tested PVT module with use of water-Al_2O_3 nanofluids with nanoparticle concentration of 3% as a coolant. The sunlight irradiance was nearly constant and ranged from 930 to 958 W/m^2. It is seen in Fig. 5 that the increase of mean temperature of the collector – especially for higher voltage drop, results in distinctly lower current generated by the PVT module. Characteristic is the stepwise course of the current-voltage characteristics independent of the voltage drop and mean temperature of the collector.

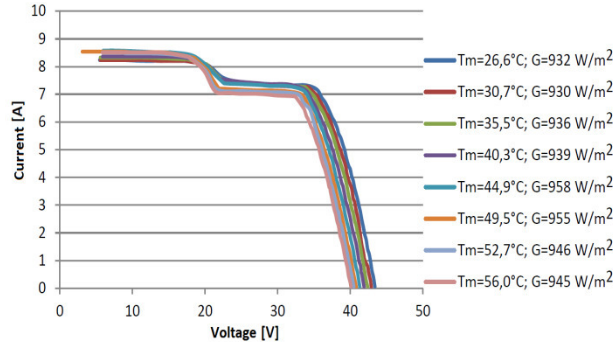

Fig. 5. Current-voltage characteristics of the PVT cooled by the water-Al_2O_3 nanofluid with nanoparticle concentration of 3%

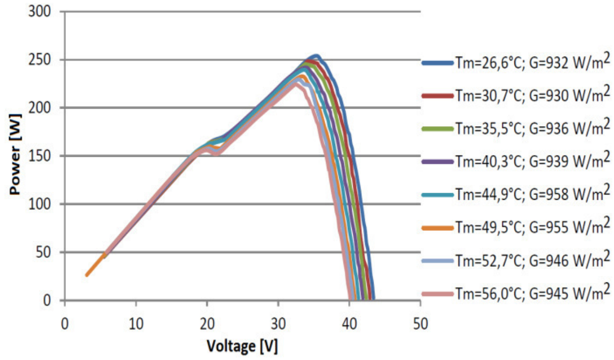

Fig. 6. Power-voltage characteristics of the PVT cooled by water-Al_2O_3 nanofluid with nanoparticle concentration of 3%

Figure 7 shows impact of the cooling fluid on the open circuit voltage versus temperature of the photovoltaic panel for the artificial source of light and sunlight. It is seen that independent of the cooling fluid the open circuit voltage decreases almost linearly with the temperature increase of the photovoltaic panel. Moreover the open circuit voltage in case of artificial source of light is about 3,5% lower than for sunlight although the irradiance of sunlight is lower than that of artificial source of light. Probably this discrepancy results from the mismatch between the spectral distribution of solar radiation and artificial radiation. Application of the water-Al_2O_3 nanofluid with nanoparticle concentration of 1% has not improved the open circuit voltage compared to water as cooling medium while the PVT was exposed to the sunlight.

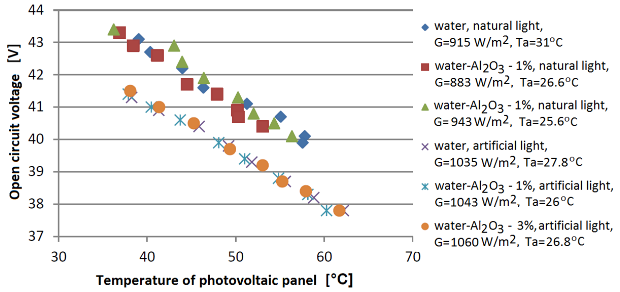

Fig. 7. Open circuit voltage versus temperature of the photovoltaic panel for sunlight and artificial source of light using different cooling fluids

Figure 8 shows the overall efficiency of the tested PVT as a function of the reduced temperature for the runs conducted with sunlight. Obtained results indicate that for lower reduced temperatures the overall efficiency of the hybrid module reaches almost 80% and linearly decreases with the reduced temperature increase. The values of the total efficiency are practically within the error range for the three tested cooling fluids, i.e. distilled water and nanofluids water-Al_2O_3 with nanoparticle concentrations of 1% and 3%.

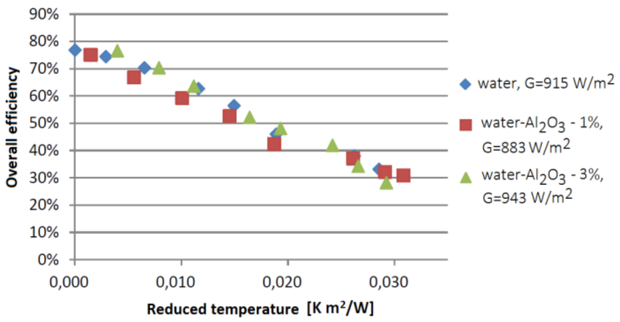

Fig. 8. Overall efficiency versus reduced temperature for sunlight

CONCLUSIONS

It was observed that the use of water-Al_2O_3 nanofluid with concentration of 1% results in lower thermal efficiency of the PVT module than for distilled water and water-Al_2O_3 nanofluid with concentration of 3% for nearly the same irradiance.

It was established that the increase of mean temperature of the collector – especially for higher voltage drop, results in distinctly lower current generated by the PVT panel.

No noticeable effect of the nanoparticle concentration on the overall efficiency of the PVT module has been recorded while using water-Al_2O_3 nanofluid as a cooling medium.

NOMENCLATURE

A	absorber surface area	m^2
c	specific heat	$kJkg^{-1}K^{-1}$
G	irradiance	Wm^{-2}
I	current	A
$\dot{m}$	mass flow rate	kgs^{-1}
$\dot{Q}$	heat transfer rate	W
R	resistance	Ω
T	temperature	K
U	voltage	V

Greek symbols

ΔT temperature difference K

Subscripts

a	ambient,
c	collector
in	inlet,
m	mean
nf	nanofluid
out	outlet
p	nanoparticles
pv	fotovoltaic
u	useful
w	water

REFERENCES

Cieśliński J.T., Dawidowicz B., Popakul A., 2016, *Performance of the flat plate solar collector operated with water-Al_2O_3 nanofluid*, Applied Mechanics and Materials, vol. 831, pp. 181-187

Daghigh R., Ruslan M.H., Sopian K., 2011, *Advances in liquid based photovoltaic/thermal (PV/T) collectors*. Renew Sustain Energy Rev, vol. 15, pp. 4156-70

Ensol, *Specifications hybrid solar collectors Ensol E-PVT 2.0.*

Gangadevi R., Agarwal S. and Roy S., 2013, *A Novel Hybrid Solar System Using Nanofluid*, Int. J. Engineering Research and Technology, vol 6, n. 6, pp. 747-752

Ghadiri M., Sardarabadi M., Pasandideh-Fard M., Moghadam A.J., 2015, *Experimental investigation of a PVT system performance using nano ferrofluids*, Energy Conversion and Management, vol. 103, pp. 468 – 476

Sardarabadi M., Passandideh-Fard M., Heris S.Z., 2014, *Experimental investigation of the effects of silica/water nanofluid on PV/T (photovoltaic thermal unit)*, Energy, vol. 66, pp. 264 – 272

Xu Z., Kleinstreuer C., 2014, *Concentration photovoltaic-thermal energy co-generation system using nanofluids for cooling and heating*, Energy Conversion and Management, vol. 87, pp. 504–512

Acknowledgements

The authors would like to thank Ensol company for the renting of the PVT collector for testing.