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THE TESTING OF ENERGY EFFICIENCY OF A PROTOTYPE HYBRID SOLAR PANEL

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Summary. The study presents results of testing of a prototype hybrid panel. The panel combines a fluid panel and photovoltaic module in one casing. The tests were performed for four positions of the hybrid panel in relation to the level and for constant southern azimuth. The tests resulted in calculation and comparison of efficiency of solar thermal and photovoltaic energy conversion for the assumed test trends.

Key words: solar panel, photovoltaic conversion, solar thermal conversion, photovoltaic cell, photovoltaic panel.

INTRODUCTION

Numerous tests of photovoltaic modules [Pluta 2003, Smoliński 1998] proved that, in the case of use of silicon cells, the efficiency of the modules decreases, by 0.4 %, on average, for each temperature degree increment. The combination of a photovoltaic module with a fluid panel in one solar hybrid panel will improve efficiency of the photovoltaic panel as a result o decrease of its temperature and will make it possible to use the heat for heating of the agent circulating in the fluid panel. One may arrive at similar conclusions when analyzing charts presenting spectral sensitivity of photovoltaic silicon cells. It results from the charts that photovoltaic modules made of silicon cells use mainly the visible spectrum of solar radiation. In turn, solar radiation spectra with greater lengths of waves (infrared) contribute to an increase in the internal temperature of the module. Due to scarce information about the type of hybrid panels, we made an attempt to construct a prototype and perform initial tests.

THE AIM AND SCOPE OF STUDY

The aim of this study was to construct a prototype hybrid panel made of a fluid panel and photovoltaic module. Another stage of this study involved testing of energetic efficiency of photo-voltaic and solar thermal energy conversion processes as well as verification of the extent, to which the hybrid panel inclination in relation to the level affects the efficiency of both types of conversion processes. The tests were performed for four inclination angles of the panel. For each inclination, solar radiation intensity was measured.

DESCRIPTION OF THE TEST STATION

Fig. 1 presents a schematic diagram of the hybrid panel abbreviated as PV/T. The hybrid panel with the measurements of 50x100 cm includes an absorber for solar thermal conversion and four strings of 32 photovoltaic cells connected in series. The total area of photovoltaic cells equals 0.2112 m^2. The prototype structure uses monocrystalline silicon cells. The basic element of the panel used in solar thermal conversion is a copper pipe with the diameter of 6 mm and total length of 5.5 m. FS 20 polystyrene with the thickness of 30 mm was used as insulating layer for the back wall of the panel.

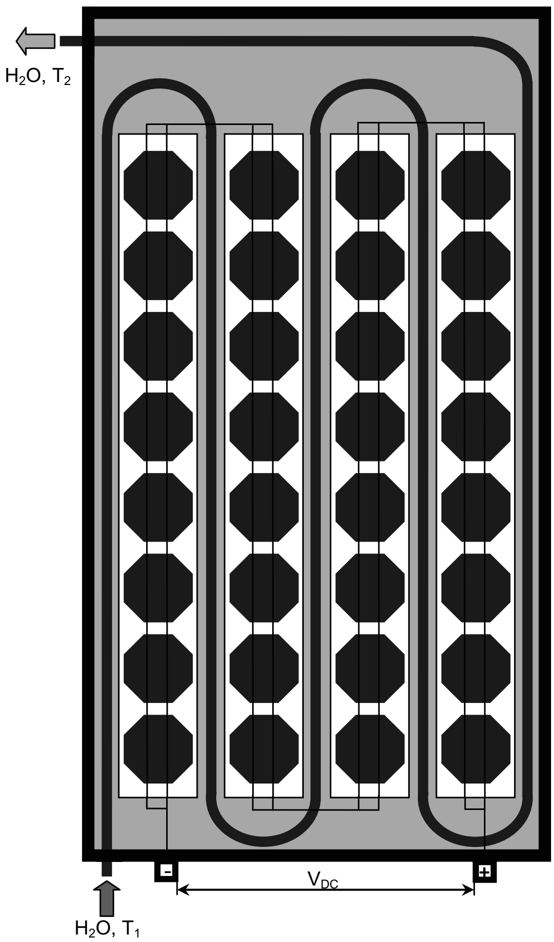

Fig. 1. The schematic diagram of PV/T hybrid panel

The flat fluid panel has a form of serpentine channels with inlet and outlet pipes extending from the enclosure. Water with stabilized temperature of T_1=296 K (23^0C) was used as an agent heated in the fluid panel. Screw terminals for direct current poles of the photovoltaic module were also extended.

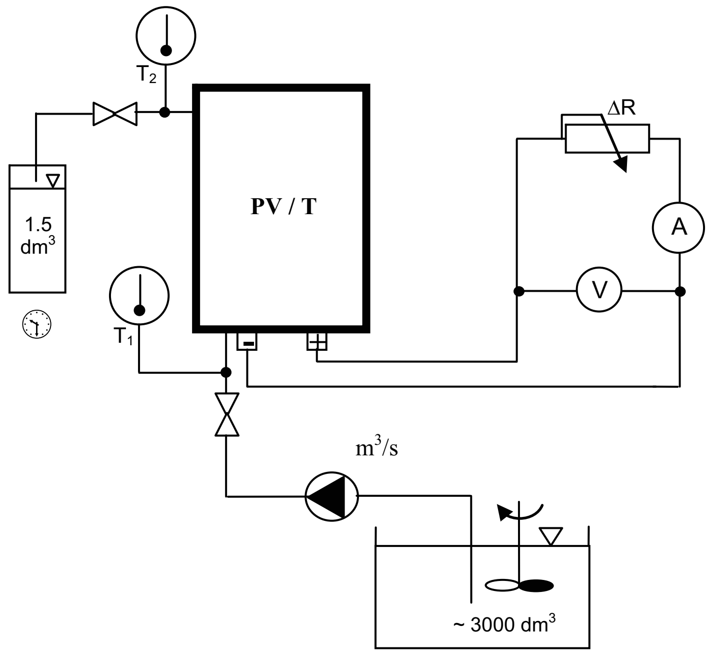

Fig. 2. A diagram of the measurement station for testing of PV/T hybrid panel

Fig. 2 presents a diagram of the measurement station for testing of the hybrid panel. The temperature of inlet and outlet water with respect to the fluid panel was determined with the use of Digital Multimeter VC 333 temperature probes with the accuracy of ±1 %. Circulation of water in the fluid panel was forced by GIRO electrical pump, model 1250.79.00. For stabilized (recurrent) flow conditions, each 1.5 dm^3 of water flowing out of the panel was measured. Measurements of the photovoltaic module (marked as PV) were made with the use of DT 9208A universal meters with the accuracy of 0.5 % for voltage range and 2 % for current intensity [Operator's manual 2006].

METHODOLOGY OF TESTS

The initial tests were performed on 9 July 2010 between 12^{00}÷15^{00} in the vicinity of Płock – GPS position: 52.61 N and 19.72 E in weather conditions corresponding to complete solar operation. Upon stabilization of the flow of water through the flat fluid panel, the stream of energy obtained from the panel ($\dot{Q}_u$) was calculated as follows:

$$\dot{Q}_u = \rho_w \cdot \dot{V}_w \cdot c_w \cdot (T_2 - T_1) \quad [W], \tag{1}$$

where:
ρ_w - water density in the temperature of 298 K (25 ^{0}C) equaling to 997.04 [kg/m^3],
$\dot{V}_w$ - water volumetric flow expressed in [m^3/s],
c_w - specific heat of water for the temperature of 298 K (25^{0}C) and pressure of 1000 [hPa] equaling to 4189.9 [J/(kg×K)],
T_1 – water temperature measured on the panel inlet pipe in [K],
T_2 - water temperature measured on the panel outlet pipe in [K].

The calculations disregard irrelevant changes of water density and specific heat values depending on changes in temperature and atmospheric pressure. The measurements of efficiency of the fluid panel were performed for four angle positions with respect to the level (β): 0^0, 30^0, 60^0 and 90^0. The panel azimuth angle was placed in the southern direction. The intensity of solar radiation was measured with the use of PL-110SM solar radiation meter manufactured by Voltcraft with the measurement accuracy of ± 5 %. The meter has a CE mark [Operating instructions 2009]. During the test, humidity and temperature conditions ensuring nominal accuracy of the meter were fulfilled. The efficiency of the fluid panel (η_{kc}) was calculated as follows:

$$\eta_{kc} = \frac{\dot{Q}_u}{S_{kc} \cdot E} \cdot 100 \qquad [\%], \tag{2}$$

where:
S_{kc} – active area of the fluid panel equaling to 0.5 m^2,
E – solar radiation intensity [W/m^2].

The test of the photovoltaic module involved the preparation of current and voltage characteristics for each angle position of the panel. The tests were performed with the use of methods proposed by the author of this study [Sarniak 2008]. The efficiency of the photovoltaic module (η_{PV}) was calculated as follows:

$$\eta_{PV} = \frac{I_{MPP} \cdot U_{MPP}}{S_{PV} \cdot E} \cdot 100 \qquad [\%], \tag{3}$$

where:
E – as in the formula (2),
S_{PV} – active area of the photovoltaic module equaling to 0.2112 m^2
I_{MPP} – direct current intensity for maximum power point [A],
U_{MPP} – direct current voltage for maximum power point [V].

TEST RESULTS

Results of tests of the fluid panel were presented in the Table 1. The calculations were made for the fluid panel water inlet temperature of T_1=296 K (23^{0}C) as stabilized as a result of mechanical stirring and with the assumption that the active area of the panel equals to S=0.5 m^2. The measurements were repeated three times in a row and the recorded values represent arithmetic values of the measurements.

Table 1. Results of tests of the fluid panel for four angle values (β) of the hybrid panel inclination

β [^{0}]	$\dot{V}_w$ x 10^{-6} [m^3/s]	T_2-T_1 [K]	($\dot{Q}_u$) [W]	E [W/m^2]	η_{kc} [%]
0	25.42	3.1	329.24	860	19,14
30	22.73	4.0	379.77	1010	18.80
60	20.83	2.2	191.47	920	10.41
90	18.99	1.8	142.78	720	9.91

The examples of tests results for the photovoltaic module in the form of current and voltage characteristics were presented in Fig. 3. The figure shows a chart presenting I-V characteristics for the hybrid panel inclination angle of 30^0.

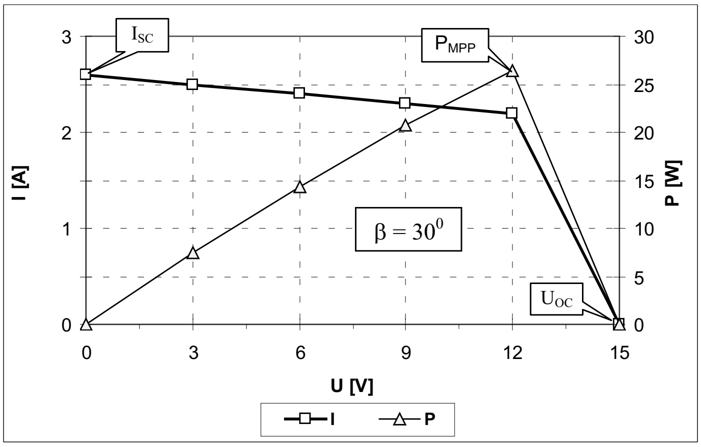

Fig. 3. The current and voltage characteristics of the photovoltaic module for the inclination angle of 30^0 in southern azimuth direction I – current, U – voltage, P – direct current power

Table 2 presents results of tests of the photovoltaic module characteristics for four values of inclination angle of the hybrid panel (β). The values were provided for characteristic points of the charts I-V: U_{OC} – open module voltage, I_{SC} – short-circuit current of the module, U_{MPP} – voltage for maximum power, I_{MPP} – current intensity for maximum power and P_{MPP} – maximum power point.

Table 2. Results of tests of basic parameters of the photovoltaic module

β [^{0}]	U_{OC} [V]	I_{SC} [A]	U_{MPP} [V]	I_{MPP} [A]	P_{MPP} [W]	E [W/m^2]	η_{PV} [%]
0	14.8	2.3	11.7	2.1	24.57	860	13.53
30	15.3	2.6	12.3	2.2	27.06	1010	12.69
60	15.1	2.4	12.1	1.9	22.99	920	11.83
90	14.6	2.2	11.1	1.7	18.87	720	12.41

In order to ensure transparency of interpretation of the results in Fig. 4, the author provided a graphic presentation of the results of tests of photovoltaic and solar thermal conversion depending on the inclination angle of the hybrid panel and solar radiation intensity. It results from the chart that the conversion process relating to the fluid panel is most affected by changes in the inclination angle and solar radiation parameters. In both cases, the greatest efficiency values are demonstrated by conversion processes for the panel inclination angles of 0 and 30 degrees.

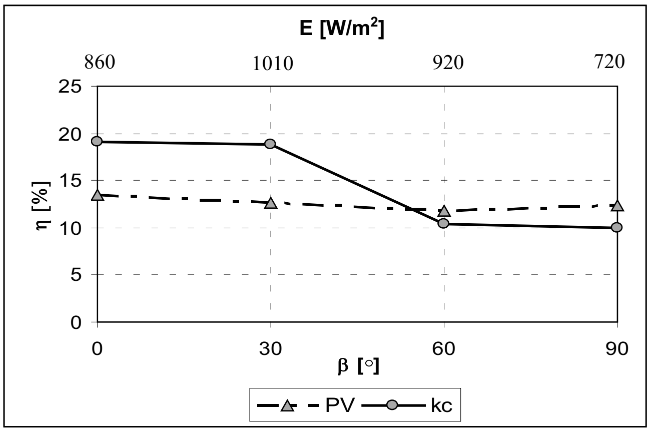

Fig. 4. Charts presenting the efficiency of photovoltaic (PV) and solar thermal (kc) conversion processes in the P/VT hybrid panel

CONCLUSIONS

1. As a result of the tests, the author states unequivocally that the combination of both photovoltaic and solar thermal conversion processes increases general efficiency of the hybrid panel, however, the efficiency will never exceed the efficiency of both the processes conducted separately.
2. A visible influence of the inclination angle changes in relation to the level of the hybrid panel upon the efficiency of the conversion processes can be observed.
3. The solar thermal conversion process conducted in the test conditions proved more sensitive to the changes of the panel inclination angle.

4. The total greatest energy stream obtained from the hybrid panel was 406.83 [W] and it reached the maximum values in both the conversion processes for the panel inclination angle of 30^0.
5. The scope of the tests should also be extended by the testing of changes of the azimuth angle in various seasons of the year and for various intensities of solar radiation.
6. The author would also recommend replacement of cells of the photovoltaic module for cells made on the basis of amorphous silicon, for which no efficiency is lost for temperature increments.

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BADANIE EFEKTYWNOŚCI ENERGETYCZNEJ PROTOTYPOWEGO HYBRYDOWEGO KOLEKTORA SŁONECZNEGO

Streszczenie. W pracy przedstawiono wyniki badań prototypowego, hybrydowego kolektora słonecznego. Kolektor ten jest połączeniem kolektora cieczowego i modułu fotowoltaicznego w jednej obudowie. Badania przeprowadzono dla czterech położeń pochylenia kolektora hybrydowego względem poziomu i przy stałym ustawieniu azymutalnym, skierowanym w kierunku południowym. W wyniku badań obliczono i porównano sprawności procesów konwersji fototermicznej i fotowoltaicznej dla założonych warunków badań.

Słowa kluczowe: kolektor słoneczny, konwersja fotowoltaiczna, konwersja fototermiczna, ogniwo fotowoltaiczne, panel fotowoltaiczny.