Study of thermal-technical parameters and experimental investigations on PV-Thermal collector

J.S. Akhatov, I.A. Yuldashev, A.S. Halimov

***Abstract* - This paper presents a short review on photovoltaic-thermal (PV-T) collectors, their design and performance evaluation, and the comparison of findings obtained by various researchers. The short review also covers a description of different designs for PV-T collectors, the results of theoretical and experimental works, focused on an optimization of technical and economical performances in terms of electrical as well as thermal outputs. Results of theoretical and experimental investigations on determination of thermal and electrical performances of PV-Thermal collector developed in Physical-Technical Institute are presented. Experimental investigations were carried out under natural conditions of Tashkent City.**

***Index Terms*— Efficiency, Photovoltaic-Thermal collector, Solar energy, Solar Cell.**

I. INTRODUCTION

The various concepts of combined PV-T collectors have been discussed and a big number of theoretical and experimental studies have been carried out over last 30 years. As it is mentioned in [1-2], the main problem is to increase the overall energy efficiency. Nowadays electricity conversion of solar cells is known; however, more than 80% of the incoming solar energy is either reflected or absorbed as heat energy. Consequently, the operating temperature of the solar cells increases considerably over a long period of operation and the cells efficiency drops significantly. The idea of using water or air as a coolant for PV-T collector technology could be considered as one of the solutions for improving the energy performance [3]. The PV-T collectors can simultaneously provide electricity, achieving a higher conversion rate than standard PV modules by reducing the operating temperature of the PV modules, and by heat extracting from PV modules and transferring to water or air [4].

According to the conclusions of many researchers, the PV-T water heating systems are more efficient than PV-T air heating systems, due to the high thermal conductivity, high heat capacity, and high density resulting in a high volume transfer. But, the using of water requires more extensive modifications to enable water-tight and corrosion-free constructions. Hence, natural or forced air circulation through an air channel on the PV rear or top or both surfaces is the simplest mode to extract heat from PV modules [1-2]. The rapid development and sales volume of PV modules is assumed to create a promising business environment in the near future. However, the current electricity cost of PV is still several times higher than of the conventional power generation. One of the ways to shorten the payback period is to bring in the hybrid PV-T technology, which increases the energy outputs from the same collector surface area [5].

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1.1 PV-T air collectors

There are different types of PV-T air collectors, which theoretically and experimentally designed and evaluated by various researches, distinguishing from each other by the airflow pattern. These are differentiated with respect to the flow of air above the absorber, below the absorber, on both sides, in single and in double pass. PV-T collector with single and double glass covers has also been investigated in [6-8]. There was proposed integrated PV module with an air duct in [9], as well as unglazed and glazed PV-T air heater, with and without tedlar [10], double-pass solar PV-T air heater with fins [11].

1.2. PV-T water collectors

PV-T water collectors are distinguished according to water flow pattern, which have differentiated to sheet and tube, channel free flow and different absorber types. For example the investigated (glass–glass) type of PV-T solar water heaters [12], flat-box aluminum-alloy PV-T water heating system with natural circulation, and the hybrid PV-T collector integrated with monocrystalline Si cells into a solar thermal collector [13]. Flat-box type of PV-T collectors have been experimentally investigated with and without glazing [14]. In addition, the photovoltaic-thermosyphon collector with rectangular flow channels is studied [15]. The TRNSYS simulation results are presented for hybrid PV-T solar systems for domestic hot water applications in both of passive and active.

In the previous works [16-17] of authors presented experimental results are obtained for PV-T collector, where Si based PV modules are used as a solar radiation absorbing surface of flat plate water heating collectors. Thus, it has experimentally shown that the temperature changes at the outlet of water heating collector during the sunny hours of a day, in a natural circulation mode of working fluid at different ambient temperatures, are almost identical. In this case, the water temperature at the outlet is quite different. In [18], the electrical and thermal yield of solar domestic hot water systems with one-cover sheet-and-tube PV-T collectors were considered. The objectives of the work were to understand the mechanisms of determining these yields, in order to investigate the measures for improving these yields and to investigate the yield consequences, if various solar cell technologies are used. The results show that both the annual electrical and thermal efficiency of systems with covered sheet-and-tube PV-T collectors are about 15%, that is lower, when compared with separate conventional PV and conventional thermal collector systems.

II. Investigations on PV-T Collector

Despite a numerous research and design solutions for the development and optimization of PV-T collectors, such designs have a number of disadvantages. First, it needs to seal the back of the PV panel in order to avoid a direct contact with the coolant and solar cell. The waterproofing increases the weight and cost of the installation, and is still the probability of coolant and its contact with the solar cell, which could lead to the closure of the circuit and premature failure of the solar cell and whole PV module in general. Secondly, the efficiency of PV-T collector has not improved by increasing of linear dimensions, as a growth in the size and mass of the fluid, respectively, increases the pressure of coolant at the PV panel and the entire structure as a whole. The improving of strength of design with additional stiffeners does not eliminate the problem as a whole and increases the cost PV-T collector.

Taking into account the factors, the task was to create a PV-T collector, which is free of above indicated disadvantages and to study its electrical and thermal characteristics. The results of measurements for the electrical and thermal characteristics of PV-T collector are presented. Fig. 1 shows a general view of PV-T collector designed and constructed in Test Base of Physical-Technical Institute, and its circuit diagram is presented on Fig.2.

Fig.1. PV-T collector (right) and PV module (left) during the tests in Test Base of Physical-Technical Institute.

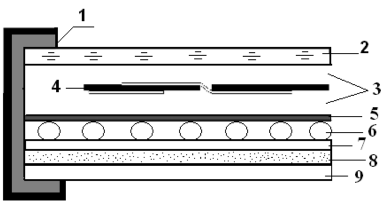

Fig.2. Principal Scheme of PV-T wafer. 1– frame; 2– tempered glass (thickness-5mm); 3- EVA; 4- solar cells; 5-Al sheet (thickness-0,3мм); 6-collector in form of «meander»; 7-reflective surface; 8-heat insulation; 9-back surface.

The developed PV-T collector on the base of the previously created PV module, which was made up of 40 series-connected solar cells based on single-crystal silicon with an efficiency of ~ 18.5% and the size is 156×156×0,2 mm. In the AM1 power PV-T was 170 W, the open circuit voltage was 23.8 V and short circuit current was 8.5 A. On the back of the PV-T protective layer of polyamide film is bonded. Solar water heater (collector) is a copper tube with a diameter of 10 mm, curved meander. The collector is in contact with the aluminum plate. PV module is an aluminum plate 0.3 mm thick. The contact area with a sheet of aluminum meander is about 5% of the aluminum sheet. The meander volume is 1.5 liters. To reduce heat loss around the perimeter of the collector, it is covered with a reflective aluminum foil. A thick layer of insulating coating on the back of a sheet of aluminum PV-T collector is fixed with thickness of 2 mm. The landing gear collected aluminum profile and has the mechanism of orientation to the sun..

III. Energy Balance

- Balance equation for the light transparent cover (glass cover and silicon hermetic);

$$I_p F_{glass} + h_{r,glass} F_{glass} \left(T_a - T_{glass1}\right) = \frac{\partial U_{glass}}{\partial t} + I_p F_{glass} \rho_{tr.cov.} + I_p F_{glass} \tau_{tr.cov.} \quad (1)$$

- Balance equation for the solar cells

$$\tau_{tr.cov.} I_p F_{glass} + \frac{k_{cell}}{\Delta l_{cell}} F_{glass} \left(T_{glass2} - T_{cell.1}\right) = \frac{\partial U_{cell}}{\partial t} + \varepsilon_{cell} \tau_{tr.cov.} I_p F_{glass} + \frac{k_{al.sheet}}{\Delta l_{al.sheet}} F_{glass} \left(T_{cell.1} - T_{al.sheet.1}\right) \quad (2)$$

(2)
- For the aluminum sheet and water flow

$$\frac{k_{al.sheet}}{\Delta l_{al.sheet}} F_{glass} \left(T_{cell.1} - T_{al.sheet.1}\right) = \frac{\partial U_{al.sheet}}{\partial t} + \dot{m} C_p \left(T_{out} - T_{in}\right) + h_{r.sheet} F_{glass} \left(T_{al.sheet.2} - T_{bet.sh.iso.}\right) \quad (3)$$

- For air between the aluminum sheet and isolation

$$h_{r.sheet} F_{glass} \left(T_{al.sheet.2} - T_{bet.sh.iso.}\right) + \frac{k_{isol}}{\Delta l_{isol}} F_{glass} \left(T_a - T_{bet.sh.iso}\right) = \frac{\partial U_{air.bet.}}{\partial t} + h_{r,isol.} F_{glass} \left(T_{bet.sh.iso.} - T_a\right) \quad (4)$$

- The unit's thermal efficiency has the following form

$$\eta_{te} = \frac{\dot{m} C_p \left(T_{out} - T_{in}\right)}{I_p F_{glass}} \quad (5)$$

IV. Results and Discussion

4.1. Simulation results

A model of thermal mode of PV-T collector was developed by using SolidWorks Flow Simulation and the result of preliminary calculations are obtained, which are described below:

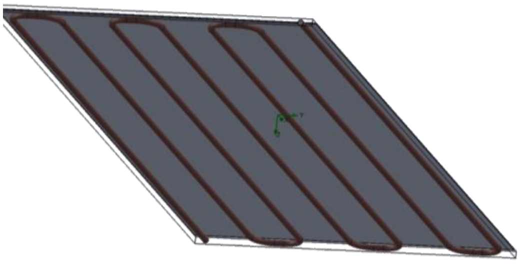

Fig.3. A general view of PV-T model created in SolidWorks

A model is developed by *SolidWorks Flow Simulation* in order to analyze the dynamics of temperature distribution of PV module and to estimate an influence of water flow on temperature of PV module. Measured data of environmental parameters have been used to simulate the heat transfer process in the model. The measured data were for May 24, 2012, which are given in Fig 4.

4.1.1 Input data

The size of model is given in Table 1 with following computational domain:

Table 1

X min	-0.886 m
X max	0.763 m
Y min	-0.348 m
Y max	0.295 m
Z min	0.045 m
Z max	0.058 m

The ambient parameters are used for the simulation of heat transfer processes with the following (see Fig 4):

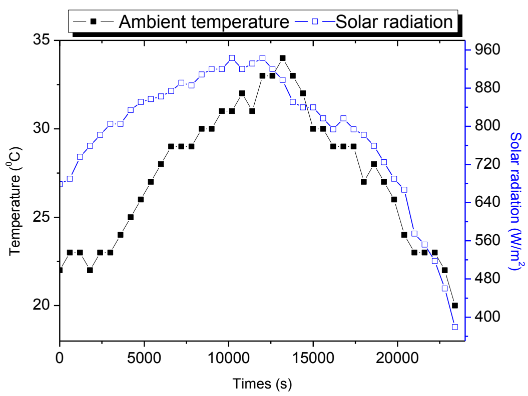

Fig.4. Dynamics of environmental parameters for May 24, 2012.

The significantly decreasing of current in PV module takes place at the peak mean of temperature of PV module is achieved. According to the main investigation, overheating of PV module occurs when the mean of solar radiation exceeds 600 W/m^2. In addition, the ambient temperature also influences on temperature of PV module, which has a significantly impact in hot regions. If it is sunny, normally, the peak mean of solar radiation could be observed between 11-00 am and 02-00 pm in condition of Tashkent. But, the ambient temperature starts increase with delay.

Based on the environmental parameters, the results of dynamical temperatures of PV module and inlet-outlet water are presented on Fig 5. For accelerating the calculation process, the peak mean of environmental parameters are used in dynamical view.

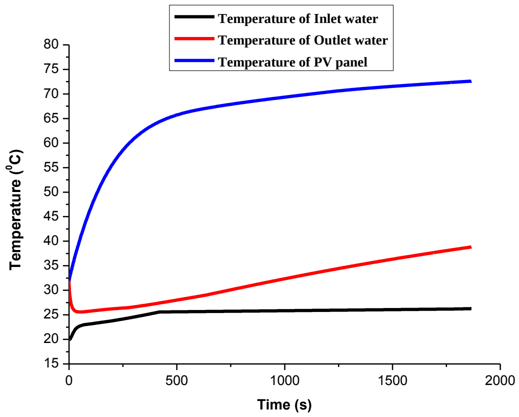

Fig.5. Dynamic temperatures of the PV module, inlet and outlet water during 11-45 am to 13-30 pm (at peak radiation) on May 24, 2012.

The main increasing of temperature of PV module starts in 10 minutes after beginning of exposure of the model by the solar radiation. It is seen on Fig 5, the temperature of PV module achieved 65 ˚C at 860 W/m^2 mean of solar radiation in 10 minutes after the start. Temperature of outlet water very slowly increases. At beginning of calculation, the temperature of inlet water has also been slowly increased by 5˚C, which could be explained by achieving of equilibrium state with the ambient parameters. The temperature distribution on PV module's surface and the temperature of outlet water in coil-tube are presented on Fig 6.

Fig. 6. Temperature distribution on the PV-T surface and coil-tube (a heat exchanger).

4.2. Experimental investigations

The results of measuring show that PV-T collector, targeted to the needs of rural residents, for the production of hot water should be pre-filled tank with 80 liters of cold water. The tank capacity depends on the performance of hot water and needs to use throughout a day. The special coating was not provided for the reservoir. The following characteristics of PV-T collector were measured: short-circuit current and open circuit voltage of the module, the intensity of solar radiation, hot water producing, capacity the ambient temperature and the temperature of the water at the inlet and outlet of the reservoir, the time of exposure. The measurements were carried out at the end of May 2012 on the Test Base of Physical-Technical Institute during the daytime from 10-00 am to 16-00 pm, the weather is clear, the wind speed at the time of measurement was constant at 1.9 m/s, the change of ambient temperature: 26°C in the morning (10-00 am), 33°C at evening (16-00 pm). After one hour from filling the tank with cold water with temperature of 23°C, measurement was performed. The water temperature at the initial time of the experiment was 56°C. Thereafter, the control valve was opened at the outlet, and the natural circulation of water came out of the collector of the PV module. The water flow rate was 14 liter per hour. The results are showed in Fig. 8 and Fig. 9.

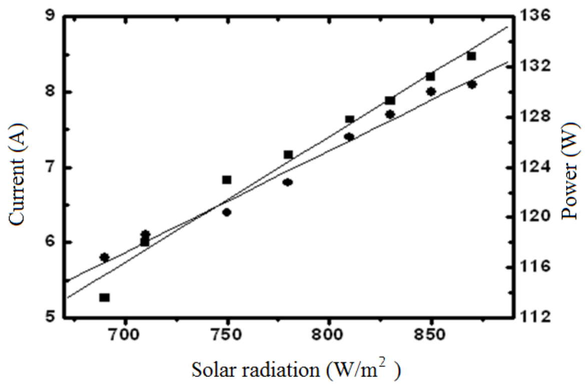

Fig.8. Experimental dependences of short-circuit current and power on solar radiation intensity

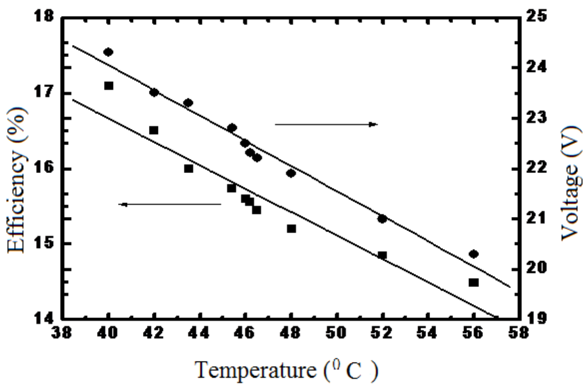

Fig.9. Dependences of efficiency and open circuit voltage on water output temperature

The open circuit voltage is reduced by 16.2%. For PV modules of conventional design, the open circuit voltage was ~ 20 V and the open circuit voltage is reduced by 17%. Progress of the conversion efficiency depending on the water temperature at the outlet of the collector is the same as in the previous case. When the water temperature at the outlet of reservoir decreased from 56°C to 40°C, the conversion efficiency increased by 3%.

Design of the collector will be improved, the portion of the aluminum sheet at the collector contact area will be increased, which should lead to increased efficiency in the production of hot water and the overall combined system.

V. Conclusions

The possibility of electricity and thermal energy generating by using PV-T solar collectors with either forced or natural flow, using air or water as a working (heat transfer) fluid were demonstrated by various researchers. In this paper, the results of theoretical investigations on determination of thermal and electrical performances of PV-T collector and their validation with the results of experimental investigations are presented. As the results show, the utilization of PV-T collectors in regions with continental climate with very hot summer period, is technically effective and stands as one of the potential solutions of the energy and water supply problems in arid areas.

Appendix

Nomenclature

I_p – ambient solar radiation (W/m^2)

F_{glass} – area of light transparent cover surface (m^2)

$h_{r,glass}$ – convective heat exchange coefficients of ambient air at surface of glass cover (W/m^2·K)

T_a – ambient temperature

T_{glass1} – topside temperature of glass cover (K)

$\tau_{tr.cov.}$ – transmission coefficient of transparent cover (%)

$\rho_{tr.cov.}$ – reflectance of transparent cover (%)

k_{cell} – heat transfer coefficient of solar cells (W/m·K)

Δl_{cell} – thickness of solar cells (m)

T_{glass2} – undersurface temperature of glass cover (K)

T_{cell1} – topside temperature of solar cells (K)

ε_{cell} – efficiency of PV module (%)

$k_{al.sheet}$ – heat transfer coefficient of aluminum sheet (W/m·K)

η_{te} – thermal efficiency of PV-T module (%)Appendixes, if needed, appear before the acknowledgment.

$\Delta l_{al.sheet}$ – thickness of solar cells (m)

$T_{al.sheet.1}$ – topside temperature of aluminum sheet (K)

$T_{al.sheet.2}$ – undersurface temperature of aluminum sheet (K)

$\dot{m}$ -flow rate of water flow in meander tube (kg/s)

C_p - specific heat capacity of water (J/kg·K)

T_{in} – inlet temperature of water (K)

T_{out} – outlet temperature of water (K)

$h_{r,sheet}$ – convective heat exchange coefficients of air between aluminum sheet and isolation (W/m^2·K)

$T_{bet.sh.iso}$ – topside temperature of isolation (K)

k_{isol} – heat transfer coefficient of isolation (W/m·K)

Δl_{isol} – thickness of solar cells (m)

$h_{r,isol}$ – convective heat exchange coefficients of ambient air at isolating surface (W/m^2·K)

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