

# PERFORMANCE COMPARISON OF HYBRID- AND FLAT PLATE SOLAR COLLECTORS

I. KOCSANY<sup>1</sup> and I. SERES<sup>2</sup>

<sup>1</sup>Szent Istvan University, Gödöllő-Hungary

<sup>2</sup>Szent Istvan University, Gödöllő-Hungary

## Keywords

Thermal efficiency, electrical efficiency, performance of PV/T collector, analysis, factors affecting

## Introduction

This paper introduced the advances and disadvantages of hybrid photovoltaic collector. After explain about detailed efficiency analysis, the further section is focused on performance differences of hybrid- and flat plate collector. Initially the solar system which was installed in the Department of Physics and Process Control, Szent István University is presented. The aim of this work is to study the behaviour of hybrid collector under different load test. The most important measured parameters and settings of the experiments are introduced. Preliminary standards and evaluation of performance reviewed.

At the Department of Physics and Process Control, Szent István University, Gödöllő various solar applications were installed for educational, demonstrational and research purposes, such as PV and solar thermal units, transparent wall insulation and solar dryer unit. The term PV/T refers to solar thermal collectors that use PV cells as an integral part of the absorber plate (Zondag, 2008). The PV/T system can be segregated into two parts, the thermal solar technology what converted the solar energy into heat, and the photovoltaic technology which derived from solar cell technology and convert the solar radiation into electricity. The hybrid collector can reduce the main problem of photovoltaic systems, the high temperature of the solar cell effects reduction in the efficiency. In order to solve that problem and get more efficiently system it is necessary to cool the PV cell and decrease its temperature.

## Calculation method

The PV/T, combining PVs into the solar thermal module, indicates a new direction for renewable energy utilizing. The examination of PV/T (installed in 2011) is performed in this paper. The solar energy technology has many advantages and disadvantages comparing to the conventional energy. The PV/T module can collect solar energy at different brands of the spectrum and lead to energy and exergy efficiency (Zondag et al., 1999). Sum of the collector's thermal efficiency ( $\eta_{th}$ ) and the PVs' electrical efficiency ( $\eta_e$ ) gives the overall efficiency (Eq. 1). Hybrid collector efficiency is defined as the ratios of useful system heat gain and electricity gain to the incident solar irradiation on the collector's absorbing surface (Chow et al., 2009) and is written as follow:

$$\eta_o = \eta_{th} + \eta_e \quad 1$$

## Efficiency of PV/T collector

Efficiency of hybrid collector is given by a thermal and an electrical part in this period the separate theory of efficiency determined.

## Thermal efficiency

The steady state thermal efficiency of a traditional flat plate solar collector is calculated by:

$$\eta_{th} = \frac{Q_u}{I} \quad 2$$

By calculating the specific heat ( $Q_u$ ) the useful collected heat from solar radiation could be determined as the multiplied by mass flow rate ( $m$ ), capacity of flowing medium ( $C_p$ ) and temperature differences of working fluid ( $T_i$  – inlet and  $T_o$  – outlet temperature of working fluid).

$$\dot{Q}_u = \dot{m} C_p (T_o - T_i) \quad 3$$

The difference between the heat losses and the useful solar radiation:

$$Q_u = A_c [I(\tau\alpha) - U_L(t_{p,m} - t_a) - Q_e] \quad 4$$

In Eq. 4 a more complex determination of specific heat can be seen where  $A_c$  is the surface of the collector,  $\tau\alpha$  is the transmittance-absorption effort of glazing cover,  $U_L$  is the overall thermal loss coefficient,  $Q_e$  electrical energy generated from the PVs,  $t_{p,m}$  is the absorber plate temperature. Hottel and Willer developed the equation of flat plate collector (Hottel et al, 1958). Because it is hard to measure or calculate the temperature of absorber plate as it is a complicated function of incident solar radiation, different collector geometry and attribution of working fluid. It is important to notice that the equations are correlated to the solar collector formation (as cylinder or rectangular shape). Some geometrical parameters in the equations could vary correspondingly if the collector shape is changed meanwhile the basic work principle of the collector remains the same.

$$Q_u = F_R A_c [I(\tau\alpha) - U_L(t_i - t_a) - Q_e] \quad 5$$

The unknown parameters are in the Eq. 5 can be determined as:  $F_R$  is the heat-removal factor,  $t_a$  is the ambient temperature.

## Electrical efficiency

The ratio of incident solar radiation to measured output power ( $P_o$ ) gives the electrical efficiency ( $\eta_e$ ) of a PV module is.

$$\eta_e = \frac{P_o}{IA_c} \quad 6$$

As it is mentioned the cells' temperature is influenced the electrical efficiency of the PV module, it is decreasing and this dependence can usually be written as (Duffie et al., 1991):

$$\eta_e = \eta_{rc} [1 - \beta_{PV} (t_{PV} - t_{rc})] \quad 7$$

Where the  $\eta_{rc}$  is the initial electrical efficiency at reference temperature,  $\beta_{PV}$  is the cell efficiency temperature coefficient, the  $t_{PV}$  is the PV cell temperature and  $t_{rc}$  is the reference temperature of PV cell.

$$T_c = T_{amb} + C_f \left( 218 + 823 \bar{K}_t \right) \frac{NOCT - 20}{800} \quad 8$$

The generated electrical energy can be calculated as follows:

$$Q_e = P_0 = \eta_e I A_c \quad 9$$

## Results and discussion

Performance of solar equipment is depending on the environmental factors, the design of the collector or PV module, materials used in it, etc. The main factors which are impact on the lower thermal efficiency of a hybrid collector when compared with a thermal collector were identified (R. M. da Silva et al., 2010). Among others due to the imperfect adhesive between additional thermal resistance and the encapsulation, the high reflection losses still appeared, energy is transmitted to the electrical production, the lower quality of absorber plate. The lower electrical efficiency when compared to a photovoltaic collector is due to the optical losses in the glass cover. A sensitivity analysis were carried out it can be seen on Fig. 1. The graph shows that the emittance of the solar cells is the most important factor in heat losses. It was verified that the angular dependence of optical properties related to the components of the radiation must be taken into account. Otherwise there can be an overestimation on electrical and thermal efficiencies in the order of 2%.

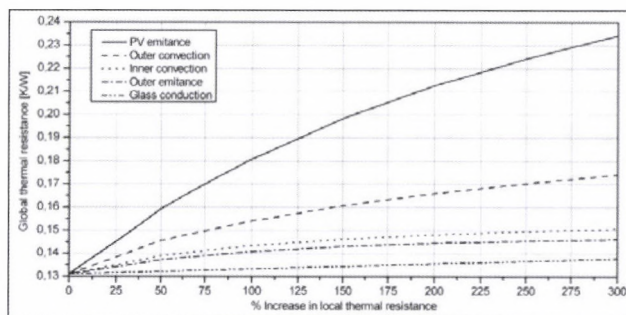


Figure 1. Sensitivity analysis on PV/T (R. M. da Silva et al., 2010)

Many factors have effect on performance of a solar equipment installation, such as: shading, corroded parts, contaminations, accessories failure, objects on solar panels, cell density, duct depth, length of collector, inlet temperature of working fluid, flow rate etc. Based on observations of experiment and literature it can be concluded that the liquid based photovoltaic thermal collector systems has better indexes in performance than air based systems (Daghigh et al., 2011). During the experiment the hybrid module was let to warm up to about 50°C, and in between the electrical output was measured (voltage and current) on a load. Meanwhile the test hybrid collector worked on a separate liquid circle, where the water was cool down by a special cooling system to around 10°C. By this way PV/T module temperature was dropped and the power change were measured. It can be seen from the following diagram (Fig. 2), that the about 10°C of drop in the module temperature caused about 1 percent of efficiency increase. It is important to notice, the PV module was not operated at its MPP during the measurement.

$$P_{thermal} = c m \frac{dT}{dt} = c \rho \frac{dV}{dt} \frac{dT}{dt} \quad 10$$

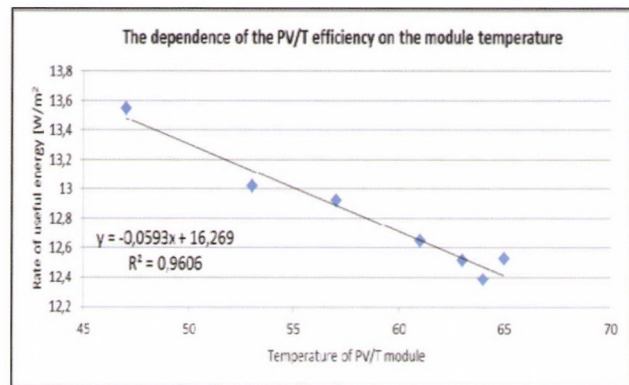


Figure 2. Rate of the module temperature and useful solar energy of a PV/T collector

By the equation above (Eq. 10) specified thermal performance determined with a comparison of the incident radiation power efficiency. However that value changing when the operating parameters are changing also, but it is characterized the operation of the device. Based on measurements calculation results can be seen on Fig. 3.

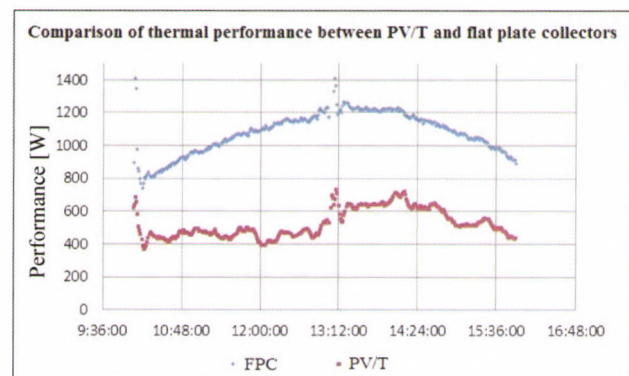


Figure 3. Thermal performance of hybrid and flat plate collectors

A comparison of thermal performance made between the hybrid and flat plate collector. Graph above show that the hybrid collector thermal performance much lower than the other one. However, it should be take into account that the hybrid collector is not specifically designed for domestic hot water. On the other hand electrical performance of the PV/T collector was compared to a polycrystalline PV module (Fig. 4).

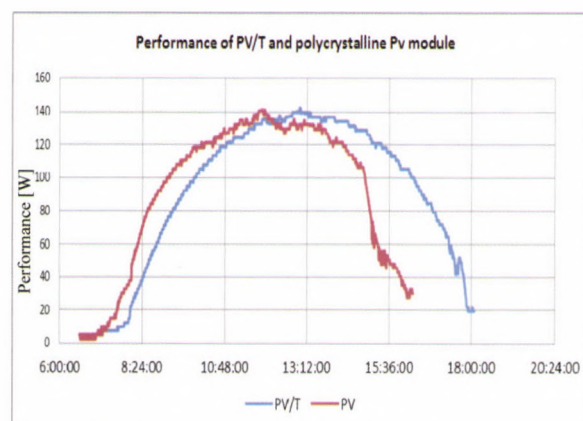


Figure 4. Electrical performance of hybrid and polycrystalline

## Conclusions

In this paper, the performance assessment of a PV/T collector was carried out. A detailed performance analysis was carried out to get a complete view of the utilized solar power of hybrid solar collectors, thermal and electrical parameters, and efficiency of different parts of PV/T collectors. From the investigation it can be concluded, that the thermal characteristic of the adhesive and working fluid flow rate has a considerable impact on the overall efficiency. In the frame work it can be concluded that the hybrid flat plate collector can be used to overcome the overheat problem of the PV system. From our examination on hybrid collector, based on measurement data it can be concluded that about 10°C temperature drops on the collector cause one percent efficiency increase.

## Acknowledgement

This work was supported/subsidized by TÁMOP-4.2.2.B-10/1 „Development of a complex educational assistance/support system for talented students and prospective researchers at the Szent István University” project.

## References

- [1] **Zondag HA.** (2008). Flat-plate PV-thermal collectors and systems: a review. *Renewable and Sustainable Energy Reviews*, vol. 12, pp. 891–959.
- [2] **Zondag HA, Vries DW, Hendel Van WGJ, Steenhoven Van AA.** (1999). Thermal and electrical yield of a combi-panel. In: *Proceedings of ISES Bi-annual Conference on CD-ROM*.
- [3] **Chow T.T., Pei G., Fong K.F., Lin Z., Chan A.L.S., Ji J.**, (2009). Energy and exergy analysis of photovoltaic–thermal collector with and without glass cover. *Applied Energy* Vol. 86, pp. 310–316.
- [4] **Hottel HC, Willier A.** (1958). Evaluation of flat-plate solar collector performance. *Transactions of the Conference on the Use of Solar Energy*, vol. 2, University of Arizona Press, Tucson, Arizona
- [6] **Duffie JA, Beckman WA.** (1991). *Solar engineering of Thermal Processes*. Second edition. John Wiley and Sons Inc., New York.
- [7] **R.M. da Silva, J.L.M. Fernandes.** 2010. Hybrid photovoltaic/thermal (PV/T) solar systems simulation with Simulink/Matlab, *Solar Energy*, vol. 84, pp. 1985–1996.
- [8] **Daghigh R, Ruslan MH, Sopian K.** 2011. Advances in liquid based photovoltaic/thermal (PV/T) collectors. *Renewable and Sustainable Energy Reviews* vol. 15, pp. 4156–4170.