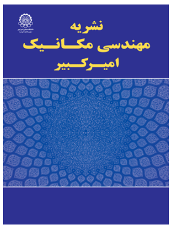

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(5) (2021) 685-688
DOI: 10.22060/mej.2020.17344.6578

# Theoretical Comparison of Thermal and Electrical Performance of Different Models of Sheet and Tube Type Solar Photovoltaic - Thermal Water Collector

S. A. Behmoonesi, F. Jafarkazemi*

Mechanical Engineering Department, South Tehran Branch, Islamic Azad University, Tehran, Iran.

**ABSTRACT:** This paper aims to compare the electrical and thermal performance of different designs of hybrid photovoltaic-thermal collectors. The main advantage of photovoltaic-thermal collectors in comparison to common photovoltaic modules is decreased cell temperature and an associated increase in their electrical efficiency. In addition, the combination of photovoltaic module and solar thermal collector makes it possible to produce both heat and electricity in a single device and reduces the area required for collector and module installation. In this research, the electrical and thermal efficiency of different designs of photovoltaic-thermal collectors is investigated. The heat transfer fluid considered for heat dissipation is water. A theoretical analysis of eight types of different photovoltaic-thermal collectors, including sheet and tube with spiral (circular cross-section) and parallel tube (circular, square and rectangular cross-sections) designs were implemented based on thermal modeling. These include collectors with different flow paths and different cross-section geometries. According to the results, sheet and tube design with circular cross-section has minimum and sheet and tube design with rectangular cross-section has maximum thermal and total efficiency. Also, glass cover reduces the electrical efficiency and increases the thermal efficiency and total thermal energy.

**Review History:**

Received: Nov. 09, 2019
Revised: Dec. 18, 2019
Accepted: Mar. 10, 2020
Available Online: Mar. 22, 2020

**Keywords:**

Photovoltaic module
Solar collector
Photovoltaic/thermal Collector
Electrical efficiency
Thermal efficiency.

## 1. Introduction

One of the problems with photovoltaic modules is the significant increase in their surface temperature due to solar radiation. The increase in temperature, reduces module efficiency. Among different methods to reduce the temperature is to remove the heat from module's backside through a fluid such as water or air. The devices that operate on this basis are called PhotoVoltaic-Thermal collectors (PV/T).

Various studies have been conducted in the last few decades to analyze photovoltaic-thermal collectors, all of which point to the superiority of the PV/T collector over photovoltaic modules. Tiwari and Sodha observed an 18% increase in the overall efficiency of the photovoltaic-thermal collectors [1]. Dubey and Tay showed that the average electrical efficiency of the photovoltaic-thermal collector was about 0.4% higher than the photovoltaic module [2]. Kazem compared the electrical performance of the photovoltaic-thermal collectors and the photovoltaic modules during three days of exposure to environmental conditions and solar radiation and showed that the PV/T had a better electrical performance [3]. Behmounesi and Jafarkazemi designed and constructed a photovoltaic-thermal collector and measured its performance in an outdoor test facility [4]. The thermal performance was investigated theoretically and experimentally.

According to the studies carried out, little research has been done to compare thermal and electrical performance of different PV/T designs. In this research, thermal modeling of the photovoltaic module and eight different designs of unglazed and glazed PV/T collectors with water as the working fluid was performed based on energy equation and the effect of some geometrical parameters was evaluated. Theoretical calculations were performed with MATLAB software. Weather data (radiation, air temperature, wind speed), inlet water temperature and physical parameters (cell material and thickness, glass cover, backside insulation, absorber, etc.) are considered as inputs and the thermal, electrical and total efficiency are calculated as outputs.

## 2. Thermal Modeling

The assumptions made to write the energy equations are a) one-dimensional heat transfer; b) quasi-steady conditions; c) negligible heat capacity for cell, tedlar and insulation; d) Almost 100% transmissivity for the EVA; e) Negligible ohmic loss for the photovoltaic module; f) Average temperature is considered for tedlar, EVA, PV glass, collector glazing and absorber plate; g) Laminar regime for the air flowing over the collector.

Three cases are modeled and compared as follows:

a) Photovoltaic module
b) PV/T collector without glass cover
c) PV/T collector with one glass cover

Water is used as the working fluid for the PV/T. Flow geometries considered are spiral tube with circular cross-section and parallel tube with circular, square and rectangular cross-sections. Governing equations are developed for each case and analyzed. The governing equations for the

*Corresponding author's email:f_jafarkazemi@azad.ac.ir

instantaneous theoretical and experimental efficiency of photovoltaic-thermal collector are as follows, respectively [5, 6]:

$$\eta_i\left(theo\right)=\frac{\dot{Q}_u\left(theo\right)}{A_c\times I\left(t\right)}=F_R\left[h_{p1}h_{p2}\left(\alpha\tau\right)_{eff}-U_L\frac{T_{f,in}-T_a}{I\left(t\right)}\right] \tag{1}$$

$$\eta_i\left(exp\right)=\frac{\dot{Q}_u\left(exp\right)}{A_c\times I\left(t\right)}=\frac{\dot{m}C_f\left(T_{f,out}-T_{f,in}\right)}{A_cI\left(t\right)} \tag{2}$$

Outlet fluid temperature under the tedlar can be determined from [7]:

$$\begin{aligned}T_{f,out}&=\left(\frac{h_{p1}h_{p2}\left(\alpha\tau\right)_{eff}\,I\left(t\right)}{U_L}+T_a\right)\times\left(1-\exp\left(-\frac{A_cU_LF'}{\dot{m}C_f}\right)\right)\\&+T_{f,in}\,\exp\left(-\frac{A_cU_LF'}{\dot{m}C_f}\right)\end{aligned} \tag{3}$$

## 3. Electrical Modeling

Electrical power output of the PV module, unglazed PV/T and glazed PV/T are calculated from Eq. (4).

$$\dot{Q}_{u,electrical}=\begin{cases}\text{PV}\;:t_G\eta_{ec}\beta_cA_cI\left(t\right)\\\text{PV/T}\;:t_G\eta_{ec}\beta_cA_cI\left(t\right)\\\text{PV/T}_{one\ cover}\;:t_gt_G\eta_{ec}\beta_cA_cI\left(t\right)\end{cases} \tag{4}$$

where Ac is the collector area and $\eta_{el}$ is module electrical efficiency which is a function of temperature as shown in Eq. (5) [8].

$$\eta_{el}=\eta_o\left[1-\gamma\left(T_c-T_o\right)\right] \tag{5}$$

where $\eta_o$ is reference module efficiency at a temperature of 298 K and solar irradiance of 1000 W/m$^2$. Other parameters in Eq. (5) may be found in [9].

## 4. Validation of Thermal and Electrical Models

In order to validate the theoretical results, outlet water temperature and efficiency were compared with the data from [2, 10]. Also, an experimental test has been done according to the procedure mentioned in [4]. The comparison of the theoretical and experimental results showed that the maximum relative error between the measured values and the theoretical calculations was less than 4%.

## 5. Results and Discussion

In this study, a photovoltaic module and eight types of plate and tube type collector were modeled in the same irradiation, ambient temperature and inlet water temperature conditions. A summary of the results can be seen in Tables 1 and 2.

The results show that increasing wind speed and inlet fluid temperature reduces the thermal efficiency of the system. To increase the thermal efficiency of the photovoltaic-thermal collector, the amount of solar radiation absorbed by the module, ambient temperature and coolant flow rate must be increased.

A comparison of the eight geometrical schemes examined is shown in Table 1. In this table, collector efficiency factor F′ is a parameter related to the proper

construction of the collector and is affected by the total heat transfer coefficient, the heat transfer coefficient of the tube, the weld heat transfer coefficient and the proper connection of the tube to the absorber plate and

the absorber plate to the back of the photovoltaic module. Heat removal factor FR is also a parameter that is related to the collector area, collector efficiency factor, mass flow rate and heat capacity of the fluid in the tube.

The total thermal energy gain and outlet water temperature in the unglazed photovoltaic-thermal collector is lower than that of the glazed one as the glazing provides better absorption of sunlight and increases the module surface temperature. According to Table 2, the circular cross-section parallel pipe design PV/T without glazing has the lowest efficiency and lowest outlet water temperature. Also, the parallel pipe glazed PV/T with rectangular flow cross-section design has the highest efficiency and outlet water temperature whereas square and spiral cross-sections have lower efficiencies. This trend is also seen in the unglazed photovoltaic-thermal collector. According to Tables 1 and 2, unglazed PV/T has higher electrical efficiency but overall efficiency is higher in the glazed type

.

## 6. Conclusions

Main conclusions of the paper are as follows: a) Although glazing increases the thermal efficiency, the unglazed PV/T has a higher electrical efficiency due to better cooling of the PV module compared to the simple PV and glazed PV/T. b) As the water temperature increases, the thermal and electrical efficiency of PV/T decreases. Therefore, to achieve

**Table 1. Comparison of the electrical efficiency of photovoltaic modules and PV/T collector at radiation 812 W/m$^2$, ambient temperature 35 $^\circ$C and inlet water temperature 43 $^\circ$C**

| Description | Symbol | Photovoltaic Module | Unglazed PV/T Collector | Glazed PV/T Collector |
|---|---|---|---|---|
| Module back plate temperature | $T_{bc}$ ($^0$ C) | 73.0 | 43.90 | 44.02 |
| Solar cell temperature | $T_c$ ($^0$ C) | 76.32 | 50.68 | 51.70 |
| Electrical efficiency | $\eta_{el}$ (%) | 9.22 | 10.61 | 10.56 |
| Output electrical energy | $Q_{u,\,el}$ (W) | 48.51 | 55.83 | 52.79 |

**Table2. Comparison of Thermal Efficiency and outlet water temperature for the four sheet and tube photovoltaic - thermal collector designs at radiation 812 W/m², ambient temperature 35 ˚C and inlet water temperature 43 ˚C**

| Description | Symbol | Unglazed PV/T Collector | | | | Glazed PV/T Collector | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Parallel tube and circular cross section | Parallel tube and square cross section | Parallel tube and rectangular cross section | Spiral tube and circular cross section | Parallel tube and circular cross section | Parallel tube and square cross section | Parallel tube and rectangular cross section | Spiral tube and circular cross section |
| Collector efficiency factor | $F'$ | 0.826 | 0.8488 | 0.8572 | 0.8525 | 0.918 | 0.930 | 0.934 | 0.931 |
| Heat removal factor | $F_R$ | 0.7822 | 0.8026 | 0.8101 | 0.806 | 0.8948 | 0.906 | 0.910 | 0.9076 |
| Useful thermal energy (W) | $Q_{u,th}$ | 225.30 | 231.17 | 233.32 | 232.15 | 291.82 | 295.48 | 296.78 | 296.0 |
| Overall thermal energy gain (W) | $Q_{u,\ total}$ | 372.22 | 378.09 | 380.25 | 379.07 | 430.74 | 434.40 | 435.70 | 434.92 |
| Outlet water temperature (°C) | $T_{f,\ out}$ | 48.38 | 48.52 | 48.57 | 48.54 | 49.96 | 50.05 | 50.08 | 50.06 |
| Instantaneous thermal efficiency (%) | $\eta_i$ | 42.82 | 43.94 | 44.34 | 44.12 | 55.40 | 56.10 | 56.40 | 56.25 |
| Total efficiency (%) | $\eta_o$ | 53.43 | 54.54 | 54.95 | 54.73 | 65.90 | 66.60 | 67.0 | 66.81 |
| Total thermal efficiency (%) | $\eta_{o,\ th}$ | 70.74 | 71.86 | 72.26 | 72.04 | 83.20 | 83.90 | 84.20 | 84.04 |

maximum output efficiency, the inlet water temperature must be close to the ambient air temperature. c) Proper design, manufacture and selection of materials increase collector efficiency factor and collector heat removal factor. d) The rectangular parallel tube glazed PV/T  has the maximum amount of useful thermal energy, total thermal energy gain, outlet water temperature, instantaneous thermal efficiency, total efficiency and total thermal efficiency. In contrast, the unglazed parallel tube design with circular cross-section has the minimum output values. e) The idea of a sheet and tube collector with rectangular flow passage cross-section may be an idea design because of its high efficiency, however, due to the cost and difficulties of manufacturing and the small efficiency reduction of less than 2% in comparison to the spiral type, it is suggested to use a spiral design (with circular cross-section) in PV/T construction.

## References

[1] A. Tiwari, M. Sodha, Performance evaluation of solar PV/T system: an experimental validation, Solar energy, 80(7) (2006) 751-759.

[2] S. Dubey, A.A. Tay, Testing of two different types of photovoltaic–thermal (PVT) modules with heat flow pattern under tropical climatic conditions, Energy for Sustainable Development, 17(1) (2013) 1-12.

[3] H.A. Kazem, Evaluation and analysis of water-based photovoltaic/thermal (PV/T) system, Case Studies in Thermal Engineering, 13 (2019) 100401.

[4] S.A. Behmoonesi, F. Jafarkazemi, Computational and Experimental Evaluation of Thermal and Electrical Performance of PV Module and Solar PV/T Water Collector, Modares Mechanical Engineering, 20(6) (2020) 0-0.

[5] A. Tiwari, M. Sodha, Performance evaluation of hybrid PV/thermal water/air heating system: a parametric study, Renewable energy, 31(15) (2006) 2460-2474.

[6] O. Rejeb, H. Dhaou, A. Jemni, A numerical investigation of a photovoltaic thermal (PV/T) collector, Renewable Energy, 77 (2015) 43-50.

[7] B. Agrawal, G.N. Tiwari, Building integrated photovoltaic thermal systems: for sustainable developments, Royal Society of Chemistry, 2010.

[8] G.N. Tiwari, S. Dubey, Fundamentals of photovoltaic modules and their applications, Royal Society of Chemistry, 2009.

[9] H.A. Zondag, D.d. de Vries, W. Van Helden, R.C. van Zolingen, A. Van Steenhoven, The thermal and electrical yield of a PV-thermal collector, Solar energy, 72(2) (2002) 113-128.

[10] H. Zondag, D. De Vries, W. Van Helden, R. Van Zolingen, A. Van Steenhoven, The yield of different combined PV-thermal collector designs, Solar energy, 74(3) (2003) 253-269.

**HOW TO CITE THIS ARTICLE**

*S. A. Behmoonesi, F. Jafarkazemi, Theoretical Comparison of Thermal and Electrical Performance of Different Models of Sheet and Tube Type Solar Photovoltaic - Thermal Water Collector, Amirkabir J. Mech. Eng., 53(5) (2021) 685-688.*

**DOI:** 10.22060/mej.2020.17344.6578