

# Performance of Photovoltaic/Thermal (PV/T) System Using Magnetic Nanofluids

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## Abstract

**P**hotovoltaic/Thermal (PV/T) systems provide hot fluid (usually water) production as well as electrical energy. However, solar cells cannot convert a large fraction of the solar radiation incident to its surface into energy, and this efficiency of energy conversion is further decreased with increasing temperature in solar cells. Although the temperature of PV cells could be lowered naturally or by cooling with a forced refrigerant, creating a hybrid system using photovoltaic panels together with thermal systems is a potential solution for increasing energy conversion efficiency. Nowadays, traditional fluids (water, air or hybrid) are used in the collector due to their thermal properties. This study aims to examine the electrical efficiency of the PV module and to evaluate both the electrical and thermal efficiency of the PV/T module. Magnetic nanofluids (1% by weight Fe<sub>2</sub>O<sub>3</sub> and Fe<sub>3</sub>O<sub>4</sub>), which are new types of flow in terms of both energy efficiency and thermal efficiency, were used. Thus, the performance and overall efficiency of the collector have been increased significantly. In the experimental study, more heat is drawn from the heated PV panels by taking advantage of the high thermal conductivity of nanofluids, resulting in an improvement of approximately 10% in electricity production. Because the amount of heat absorbed in thermal system is high, an average of 14% temperature increase was obtained in the hot fluid temperature compared with the base fluid water. Some thermodynamic specific heat capacities and material densities of 1% doped magnetic nanofluids (Fe<sub>3</sub>O<sub>4</sub> and Fe<sub>2</sub>O<sub>3</sub>) used in the study (4179.994 ; 4116.54 J/kg.k) and (1003.37; 1009.735 kg/m<sup>3</sup>).

**Keywords:** *PV/T, Nanofluids, Magnetic Nanoparticles Hybrid Systems*

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## I. INTRODUCTION

Advances in technological developments and rising human population increase the use of fossil fuels that cause global warming and environmental pollution, largely due to increased carbon dioxide emissions. The scarcity of natural energy sources, which raises global concern, results in energy security crisis and utilization of fossil fuels resulting in increased greenhouse gas emissions, severe environmental pollution and climate change. Due to the increasing global energy demand, efforts to use energy efficiently and promote environmentally friendly energy sources have increased significantly, especially in recent years. In this context, reducing the tendency to fossil fuels by encouraging the use of renewable energy sources has become one of the main objectives of the many local and international energy regulatory bodies and institutions.

Among many renewable energy sources, solar energy has gained the attention of many energy investors and industries because it is abundant, continuous, renewable and free. One of the limitations in solar energy is the efficiency of conversion of solar radiation incident to its surface into energy, which is further decreased with increasing temperature in solar cells. It has been known that a hybrid system reduces the need to use an external source of electrical energy. Many studies have been carried out to remove excess heat from the system by using gas and liquid fluids. These studies, which used water as a refrigerant in the experiment, had achieved higher efficiency than other similar studies. In contrast, other system utilizes air, which is feasible because air cooled PV-T panels are easier to implement and do not need a liquid cooling circuit. Also, air is affordable, clean and usable for almost all applications on Earth. In terms of efficiency, air cooled PV-T panels are more inefficient than water-type cooling systems.

The main reason of using water as cooling agent in this experimental study is to test and obtain more information whether this approach would improve the efficiency. Nowadays, many researches, including experimental and numerical studies on the subject, have been conducted. İbrahim *et. al.* [1] included a classifi-

cation of PV/T systems in their research as Flat Type PV/T collectors as shown in Figure 1.

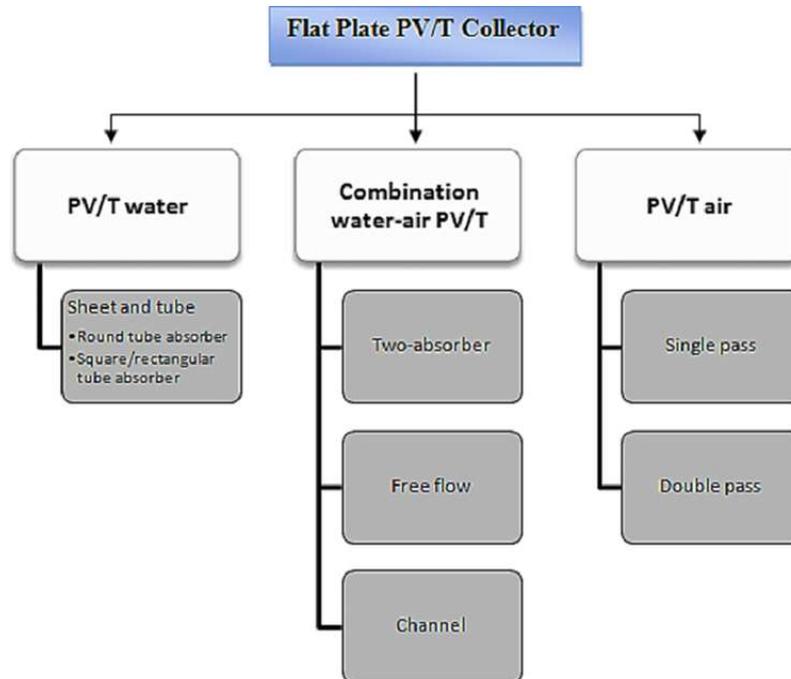


Figure1. PV/T collector type

In the study of Serhaddi et al. [2], the calculation of electrical and thermal parameters, exergy components and exergy efficiency of a PV/T air (air fluid) collector were carried out as energy and exergy analyses. In this study, a computer program was developed to calculate the thermal and electrical parameters of the PV/T collector. The electrical efficiency, thermal efficiency, total efficiency and exergy efficiencies of the PV/T collector for certain climatic, operational and design parameters were found to be 10.01%, 17.18%, 45%, and 10.75%, respectively [2]. Kim *et. al.* [3] carried out an experimental investigation of the PV/T collector whose PV panel is of monocrystalline material. In this study, air was used as a fluid to generate thermal energy in the PV/T collector. Results of the study showed that the thermal efficiency of the PV/T collector is about 22% and the electrical efficiency is about 15% [3]. Saygin *et. al.* [4] investigated a modified PV/T collector through which air

is passed as a fluid in their work. The ambient air taken from a space in the middle of the collector is passed through the upper and lower parts of the PV panel, and is discharged through a channel after the thermal energy in the PV panel is taken. In this study, the highest thermal efficiency of 48% was obtained in situation where the mass flow rate of the fluid is 0.037 kg/s and the distance between the PV panel and the protective glass layer is 3 cm [4]. Ahn et al. [5] reported that the thermal efficiency of PV/T increased by 23% with 15% electrical efficiency when the fluid (air) leaving the system was mounted in the heat recovery section to preheat the fresh air at the outdoor air inlet. In another study, Kabul and Duran [6] also observed an increased efficiency of the PV/T when the system is cooled with the help of water, and cooling the panel with the fluid (water) passed through the cooler pipes placed on the back (back) surface of the PV panel [7-9].

Photovoltaic cells decrease in efficiency with increased temperature due to increasing resistance. To reduce the resistance, the PV/T systems can be designed with cooling mechanisms to remove the heat from the PV cells, thereby cooling the cells and increasing their efficiency. It has been demonstrated that a cold-running PV panel has a higher efficiency and longer lifespan while the hot fluids could be used for residential, commercial or industrial applications.

For monocrystalline (c-Si) and polycrystalline (pc-Si) silicon solar cells, it has been observed that the efficiency decreases by about 0.45% for every 0.45°C increase in temperature. For amorphous-silicone (a-Si) cells, this effect is less observed due to slight increase in temperature of about 0.25% depending on the module design. These undesirable effects could be mitigated through heat reduction strategy, such as heat extraction through proper fluid circulation [7]. Using PV/T modules is more advantageous in terms of electrical efficiency and total efficiency (electrical + thermal efficiency) instead of standard PV panels. Although, there are other many industrial examples of systems based on solar energy, the use and production of electrical-thermal hybrid systems are limited. This study aims to examine the electrical

efficiency of the PV module and to evaluate both the electrical and thermal efficiency of the PV/T module.

## II. MATERIALS AND METHODS

All experimental studies were carried out within the Ankara air and solar environments. The analysis and traditional water data doped with experimental magnetic nanofluids were carried out in Gazi University Energy systems engineering advanced laboratory. Table 1 summarizes the list materials used in the experiment, modules, and properties. The photovoltaic panel is in both modules, but the cooling water coil is only in Module 1. The photovoltaic panels used in the experimental set have the same dimensions properties. Photovoltaic solar panels are mounted on the same platform.

Table 1. List of Materials, Modules, and Properties

Systems	Module	Properties/Description
PV Panel	1 and 2	Elism60m-hc-hv-370wp, Voc:41.6 volt,Isc:11.34 A, Vmp:34.6 volt,Imp:11.34 A
Advanced Scanner System	1 and 2	Elimko 680,Mesurement sytems:Thermo couple
Water coil	1	Copper( $\lambda$ :394 W/mK)
Solarimeter	1 and 2	Cem Dt-1307, measuring range:200 W/635 btu
Debimeter	1	Debi range:0-10L/min
Charge Resistance	1 and 2	4 ohm.

Module 1 (PV/T) and Module 2 (PV) are designed with two photovoltaic panels of the same brand and same power requirements (Figure 2). Module 1 has a serpentine tube array chiller located behind the photovoltaic panel. Before the serpentine is formed, the copper pipes are crushed to a certain extent to ensure full contact with the panel back, hence, the contact surface with

the PV module is increased. Module 2 has no additional parts, in which the panels are placed on the same two profile pipes so that both modules can be at the same angle. The serpentine inlet in Module 1 was fed with mains water and the serpentine outlet was left free to the outside environment. A flow meter was used to control the water entering the serpentine.



Figure2. Experimental Set-up of PV/T and PV Modules

### Preparation of the Magnetic Nanofluid.

A two-step method is used in the preparation of the magnetic nanofluids (MNF). The top-down method is applied to produce magnetite ( $\text{Fe}_3\text{O}_4$ ) and ( $\text{Fe}_2\text{O}_3$ ) nanoparticles. A Spex type, high-energy ball mill, ball crushing techniques were also performed. Both  $\text{Fe}_3\text{O}_4$  and  $\text{Fe}_2\text{O}_3$  magnetic nanoparticles were scattered in distilled water, with concentration ratio of 1% (wt.), as a base fluid. Then, a 0.2% (wt.) Triton X-100 was dropped into the mixture to prevent nanoparticles' agglomeration obstacles. Before starting the experiments, all suspensions were exposed to ultrasonic vibration inside an ultrasonic bath (ISOLAB Laborgeräte GmbH) for 3 hours.

## Measurement of Thermophysical Properties

The physical characteristics of the  $\text{Fe}_3\text{O}_4$ /water and  $\text{Fe}_2\text{O}_3$ /water magnetic nanofluid, such as density and specific heat, were determined using the formulae as presented in Pak et al.'s [4-8]. The density of the MNF is calculated using Equation 1.

$$\rho_{MNF} = \rho_{base} \cdot (1 - \varphi_{MNP}) + \rho_{MNP} \cdot \varphi_{MNP} \quad 1$$

Where:

$\rho_{MNF}$  = the density of the MNF ( $\text{kg}/\text{m}^3$ )

$\rho_{base}$  = the density of the base fluid (i.e., water) ( $\text{kg}/\text{m}^3$ )

$\varphi_{MNP}$  = concentration ratio (%)

The specific heat of the MNF is calculated by Equation 2. [8]

$$c_{p,MNF} = \frac{\rho_{base} \cdot c_{p,base} (1 - \varphi_{MNP}) + \rho_{MNP} \cdot \varphi_{MNP} c_{p,MNP}}{\rho_{MNF}} \quad 2$$

Where:  $c_{p,MNF}$  = the specific heat of the MNF  $\text{J}/\text{kg}\cdot\text{K}$ ;  $c_{p,base}$  = the specific heat of the base fluid (i.e. water)  $\text{J}/\text{kg}\cdot\text{K}$ , The specific heat of the magnetic nanoparticles  $c_{p,MNF}^0$  of the  $\text{Fe}_3\text{O}_4$  and  $\text{Fe}_2\text{O}_3$  is calculated by Equation 3.

$$c_{p,MNF}^0 = a + b \cdot t + c \cdot t^2 + d \cdot t^3 + \frac{e}{t^2} \quad 3$$

Where:  $t$  = temperature (K)/1000;  $c_{p,MNF}^0$  = Specific heat ( $\text{J}/\text{mol K}$ );  $M_w(\text{Fe}_3\text{O}_4) = 231.533$ ;  $M_w(\text{Fe}_2\text{O}_3) = 159.688$ . The value of the constants in equation 1 for both  $\text{Fe}_3\text{O}_4$  and  $\text{Fe}_2\text{O}_3$  MNPs are given in Table 2. Thermophysical properties were calculated using equations 1 and 2, which is given in Table 3.

**Table 2. Constants in Equation 1, for Fe<sub>3</sub>O<sub>4</sub> and Fe<sub>2</sub>O<sub>3</sub> MNPs.**

Fe <sub>3</sub> O <sub>4</sub>	Fe <sub>2</sub> O <sub>3</sub>
a = 104.2096	a = 93.43834
b = 178.5108	b = 108.3577
c = 10.61510	c = -50.86447
d = 1.132534	d = 25.58683
e = -0.994202	e = -1.61133

**Table 3. Thermophysical Properties of the Working Fluids.**

Thermophysical properties	Fe <sub>3</sub> O <sub>4</sub>	Fe <sub>2</sub> O <sub>3</sub>	Pure water
specific heat $c_{p,MNF}$ (J/kg.k)	4179.994	4116.54	4180
Density $\rho_{MNF}$ (kg/m <sup>3</sup> )	1003.37	1009.735	997

### III. RESULTS AND DISCUSSION

The average temperature of the panel surfaces between the Module 1 (PV/T) system and the Module 2 (PV) system is presented in Figure 3. It can be observed that the highest surface temperature difference between module 1 and 2 is about 14.2 °C, suggesting that module 1 resulted in significant the cooling of the panel. In the PV/T system, the amount of cooling was increased by using two different fluids, water and nanofluid. Figure 3 shows that more heat was withdrawn from the panel, using nanofluids, resulting in a lowering of temperature and cooling effects.

Figure 4 demonstrates the variations of electrical efficiencies and thermal efficiencies of the panel, which is presented as total efficiencies. As can be observed, the nanofluid increased the thermal efficiency and total efficiency. Figure 5 summarized the percentage values of these improvements. It can be observed that the change in total efficiency is about 20%, and the improvement in thermal efficiency was around 50%.

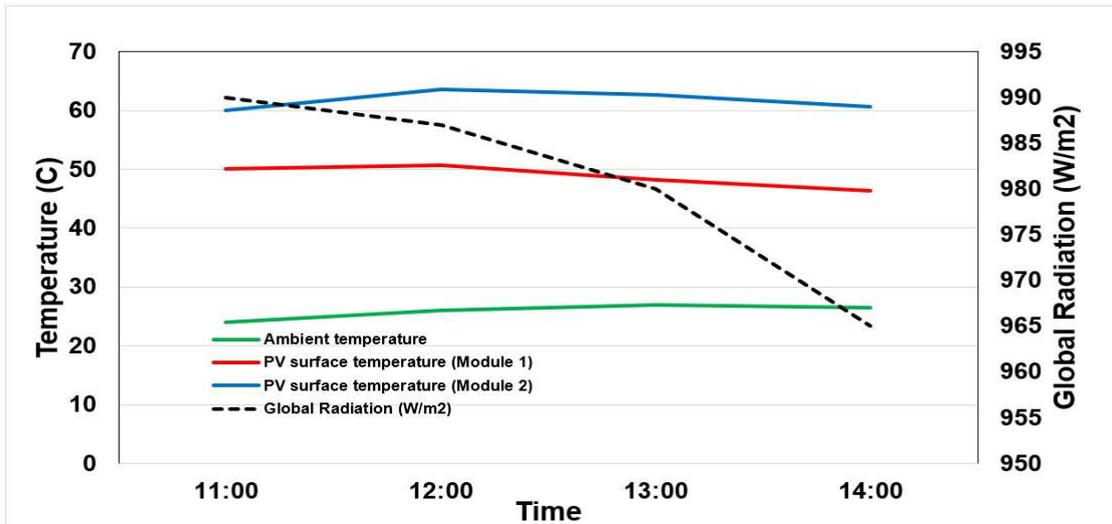


Figure 3. Temperatures Measured on the Panel

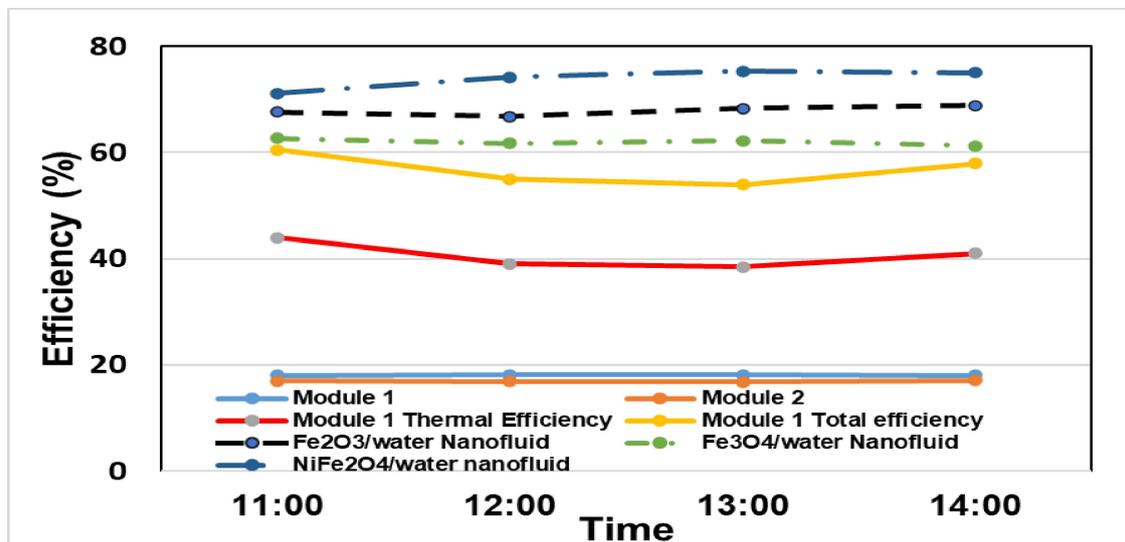


Figure 4. PV/T and PV Efficiencies

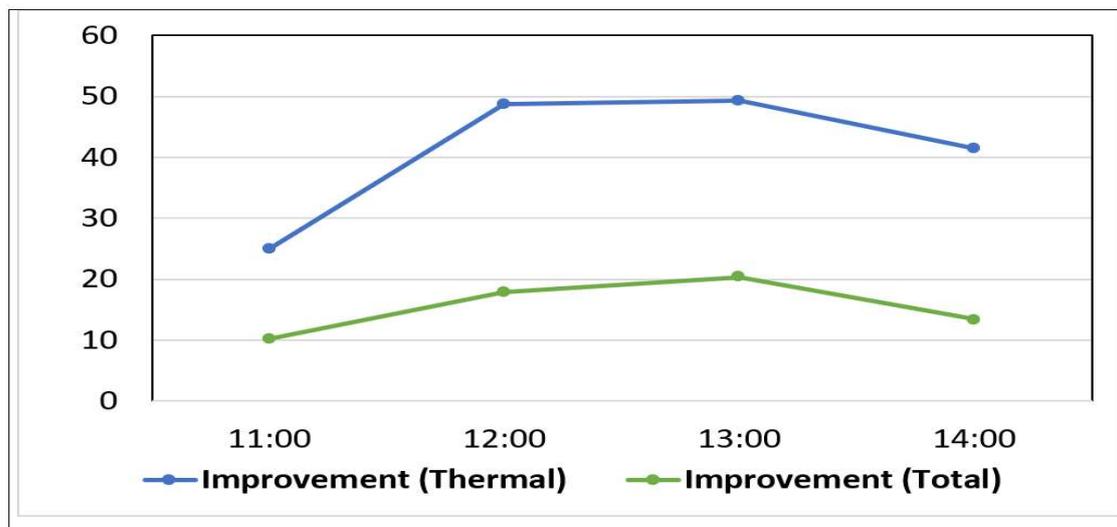


Figure 5. Improvement of Thermal and Total Efficiency

#### IV. CONCLUSION AND RECOMMENDATION

PV/T systems are one of the subjects that scientific studies have focused on in recent years. The main reason for this is to increase the electricity generation performance of PVs, as well as to obtain thermally hot fluid from the system. The fact that the obtained hot fluid has many application areas such as space heating, heating of greenhouses, use in drying systems, use as a heat source in heat pumps also causes PV/T systems to gain importance. The main physical events that cause the heat transfer performance of nanofluids to improve significantly can be summarized: (i) increase in the thermal conductivity of the prepared nanofluid, as the thermal conductivity of the solid metal is higher than that of the basic fluid, (ii) increase in the thermal transfer surface area due to the increase in the thermal conductivity of the fluid, (iii) increase in the effective thermal capacity of the fluid and (iv) increased thermal conductivity of the liquid due to high fluid activity and turbulence volume. In this study, an increased bidirectional performance was achieved by using nanofluids obtained through adding 1% by weight of  $\text{Fe}_2\text{O}_3$  and  $\text{Fe}_3\text{O}_4$  magnetic nanoparticles into the basic fluid water and increasing the thermal function of the PV/T system, hence, providing more cooling of the PV system.

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