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# Enhancement of PV/T Solar Collector Efficiency Using Alumina Nanoparticles Additives

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**ABSTRACT**

This study explores the performance of the Photovoltaic/Thermal system using nanofluid with a novel collector design. Experiments were carried out on the University of Technology- Iraq campus. An experiment was carried out using two photovoltaic modules, one connected to 120 protrusions arranged eight columns by 15 rows (for comparison) and the other not. Nanofluid was used to cool solar panels with flow rates of 1.5 and 3.5 l/min. The nanofluid contains nano-$Al_2O_3$ at 1%, 2%, and 3% concentrations in water. As the flow rate of water used as a cooling fluid increased, the surface temperature of the cell decreased. The cell temperature is reduced by 22.3% when $Al_2O_3$/water is added at a volumetric concentration of 3%. An increase in the electrical and thermal efficiency of PV/T systems was also recorded by 12% and 18.4%, respectively, at a concentration of 3%.

## 1. INTRODUCTION

Nowadays, the use of nanofluids has increased in thermal systems, especially those that depend on solar radiation, due to its physical and chemical properties, the most important of which is improving the thermal conductivity of the system [1-3]. One of the techniques applied for cooling PV panels is using water as a coolant in solar thermal collectors of PV/T systems to study the effect of cooling on the performance of the photovoltaic cell [4, 5]. All studies demonstrated a significant increase in the electrical efficiency of the PV panel compared to the same PV panel without the use of cooling [6-9]. Increasing theoretical research and various experimental studies to test the thermal properties of nanofluids and their impact on the efficiency of solar power systems, including PV/T system, by controlling the mixing ratios of these materials added to water and their types, and testing the appropriate volumetric flow rates of nanofluids, and other variables [10-16]. While several studies dealt with the efficiency of photovoltaic panels within PV/T systems with the use of nanofluids and compared them to the efficiency of the photovoltaic unit without cooling or cooled with water only and without nano additives [17-20]. Sardarabadi et al. [21] used nano-ZnO with water as a nano-cooling fluid in a solar thermal collector with mixing ratios by weight 1% and 3 wt.%. The study concluded that the system's overall efficiency increases by 3.6% when using nanofluid with 0.01% than when using pure water, and it increases by 7.9% when using nanofluids with a mixing ratio of 0.03. Gangadevi et al. [22] studied the effect of using $Al_2O_3$ with water to cool the PV system, and the cell performance was also tested, where mixing ratios of 1 and 2 by wt% of nanoparticles with water were used, at a volumetric flow rate of 40 liters / hour, and the improvement was in the level of electrical efficiency with a value of 13% and 45% respectively. The researchers obtained a PV/T system efficiency ranging from 75% to 90% compared to the standalone PV efficiency without cooling, in which its efficiency ranged between 9.9% to 10.6% [23].

For many years, water and air have been used to cool photovoltaic cells in PV/T collectors where the designs differed according to the type of heat transfer medium. Also, note that air-worked systems are more economical in cooling photovoltaic cells, but on the other hand, air has a relatively low heat transfer rate [24]. Whereas, water-based systems are more expensive, but they are more efficient due to the increased heat transfer due to their higher thermal conductivity [25]. Therefore, with the improvement in thermal conductivity by adding nanomaterial's in water, it will positively affect heat transfer performance [23]. A study on the effect of different nanofluids on the thermal/electrical efficiency of a PV/T system was done by Zhang et al. [26]. All tests were sured that nanofluids used as thermal recovery fluids provide better thermal and overall efficiency than water and ethylene glycol under similar conditions.

In comparison to basic fluids like water and oil, nanofluids have been discovered to have improved convective heat transfer coefficients, viscosity, thermal conductivity and thermal diffusivity. It has appeared a high range of possible applications. Some significant difficulties must be stressed for a two-phase system. One of the most important issues is the stability of nanofluids. The review articles involving the progress of nanofluid investigation were published by several researchers [26, 27].

In addition, many studies have confirmed that thermal efficiency ranges from 65% to 80% [28]. Othman et al. [29] performed a numerical analysis of a solar thermal collector system for the purpose of studying the effect of some operational elements on the performance of the collector, where he used nano materials mixed with water as a coolant for the purpose of reducing the temperature of the photovoltaic cell. Where the researcher concluded that $Al_2O_3$/water gave better results than $TiO_2$/water nanofluid at the same bump rate. The researcher also concluded that the electrical power produced when using nano fluids at a flow rate of 0.03 kg/s is higher than those values that were obtained using flow rates of 0.0005 kg/s, 0.001 kg/s and 0.01 kg/s. The theoretical model examined various characteristics, including flow rate, solar radiation, and air temperature, and decided that the collector should be a heat collector with a flat plate and a glass plate [30-32].

An experimental study of a new PV/T cooling collector design is presented in this paper. This study investigates the thermal and electric performance of newly designed PV/T systems using alumina nanoparticle additives. Several experiments were conducted using an experimental test rig designed and built for this purpose.

## 2. EXPERIMENTAL IMPLEMENTATION

### 2.1 Experimental setup

The current research deals with the experimental validation of the design of the PV panel cooling system for power generation. An open-flow flat heat collector is adopted to cool the back surface of the PV panel through the water flow in a closed circuit. A high conductivity paste was used in the contact area between the thermal collector and the back surface of the typical photovoltaic panel to increase the heat dissipation. All tests and data collected on the PV/T system were synchronized to the PV system without cooling to get a description of the features of the PV/T system, where part of the generated power was invested as electricity instead of heat, as shown in Figure 1. Both PV system and PV/T system are installed at an inclination angle of 30° from the horizontal. Use an effective temperature measurement system for different areas of the PV/T system, including the front and back surfaces of the collector, as well as the inlet and outlet of the water from the collector. The water flow rate was also measured using a flow rate measuring device. The water flow is controlled using a one-way valve. The main feature of the open flow flat collector is the heat transfer from the back surface of the PV panel based on the water flowing inside it. Therefore, the interior design of the complex, including providing a suitable space for heat exchange and engineering waterways, is the basis for the success of the design, in addition to the difference in temperature between the water entering the complex and the surrounding air. The new design of the collector relied on fixing fins on the outer flaps of the collector to increase the contact area and to allow heat exchange for a longer period compared to the water flow when the collector casing is without fins. The new design includes the installation of spherical fins. This system contains 120 spherical fins, with a diameter of 25 mm, and it is made of aluminum, which is characterized by its thermal conductivity on heat transfer. These fins are distributed in a matrix of 12×10, as shown in Figure 2.

**Figure 1.** Schematic view of the experimental setup

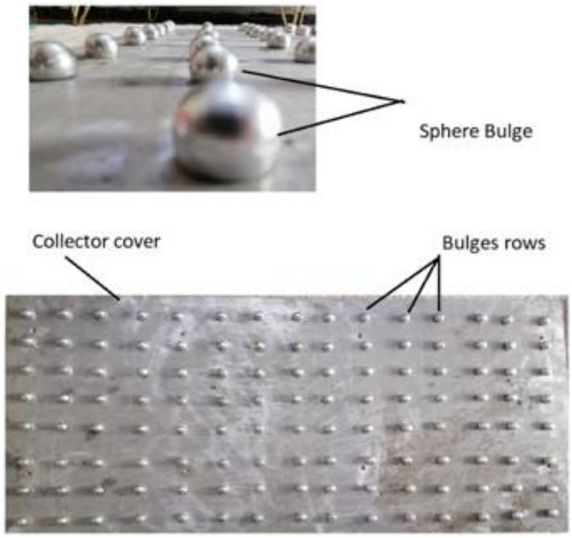



**Figure 2.** Structural pictures of an open-flow flat collector

### 2.2 Measurement and instrumentations

Temperature measurement tests were carried out to conduct an experimental investigation of this study. Experiment procedures were performed on sunny days, with cloudy or cloudy days avoided during testing. All temperature tests on the PV/T model were performed to become acquainted with and confident with the measuring procedure. Experiment measurements were carried out at the solar research facility, where two PV panels, one of which included the collector installed.

The experimental verification included the preparation of a temperature measurement system for both the PV/T system and the PV system, where the temperature sensors were distributed in several groups; Three thermocouples for measuring the surface of the photovoltaic panel within group (A), and two thermocouples for measuring the temperature of water entering and leaving the collector within group (B), while group (C) has three thermocouples for measuring the surface of the collector, as shown in Figure 3. All of these thermocouples were Type-K with selector switch and digital thermometer. Table 1 shows all the specific characteristics of all parts of the temperature measurement system. A TM-936 reader type with an accuracy of ± (0.2% + 0.5°C) was used to capture temperature readings.

**Table 1.** All specific properties for all parts of the temperature measurement system

| No. | Type of Thermocouples | Position | Accuracy |
|---|---|---|---|
| 1 | Probe type-K | 2 points, inlet and outlet collector (Grop B) | ± 0.3 |
| 2 | Wire type -K | 6 points on the PV panel and PV/T system | ± 0.2 |
| 3 | Wire type-K | 3 points on the Collector cover | ± 0.2 |
| 4 | Wire type-K | 4 points, to measuring Ambient temperature, collector body | ± 0.2 |

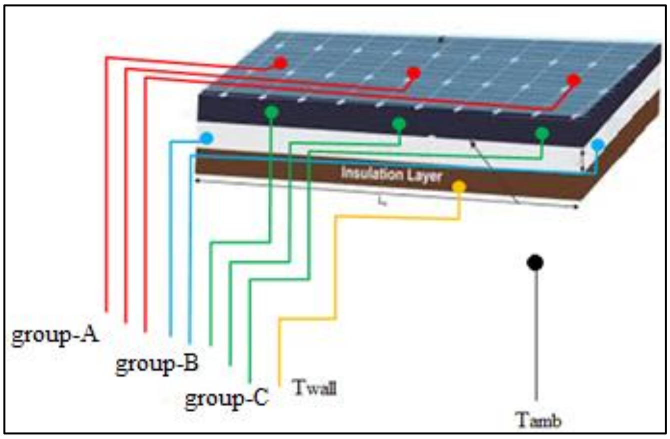



**Figure 3.** Positioning schematic of temperature measurement in the PV/T system

### 2.3 Experimental procedure

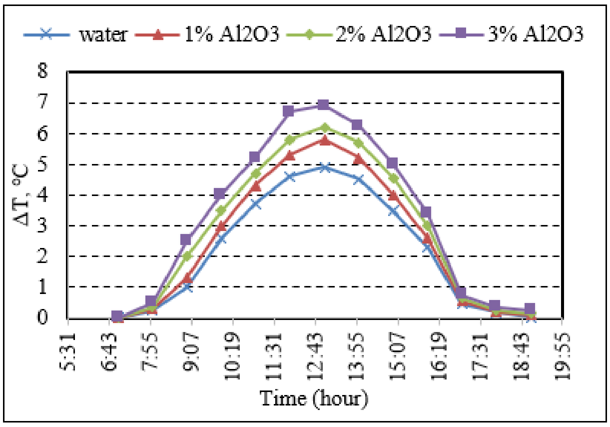
**Table 2.** Experimental results of the measured properties

| | Pure Water | $Al_2O_3$ (20 nm)- Water | | |
|---|---|---|---|---|
| Concentration (% wt.) | 0 | 1 | 2 | 3 |
| Density (kg/m$^3$) | 995.7 | 1025.4 | 1055.2 | 1084.9 |
| Specific heat (kJ/kg.K) | 4.183 | 4.051 | 3.926 | 3.808 |
| Viscosity (N.s/m$^2$) [×10$^3$] | 0.998 | 1.0827 | 1.18 | 1.26 |
| Thermal cond. (W/m·K) | 0.599 | 0.867 | 1.11 | 1.78 |

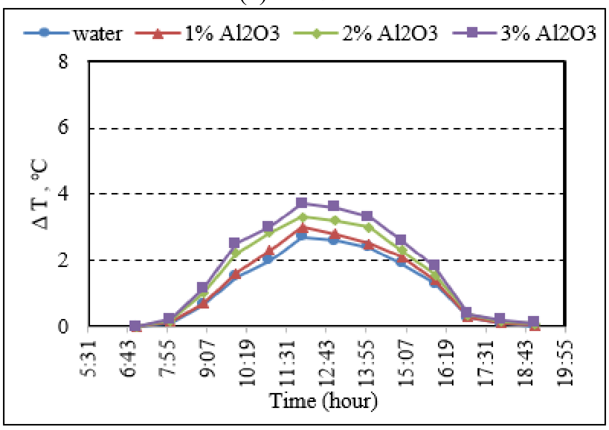
The experimental procedure was used in the outdoor measurement technique. Experiment procedures were conducted on sunny days, with cloudy or cloudy days avoided during testing. To become acquainted with and confident with the measuring procedure, basic tests of water temperature, surface temperatures, wind speed, water flow rate, and solar intensity were performed at various positions of the PV/T system. Also, the period time ranges were chosen from 7:00 am to 7:00 pm to provide a range for studying the effect of PV panel heating due to solar radiation on its performance. The experiments for open flow flat collector were conducted by temperature measurement system and water circling system for recording PV panel surface temperature, water inlet, and outlet temperatures, as well as collector surface temperature from a collector with varied alumina nanoparticles additives at several days. Also, a solar meter was used for solar intensity measuring through daily time. Table 2 shows the experimental results of the measured properties. In order to improve and increase the thermal conductivity of the heat transfer fluid, additive nanofluids must be prepared, which is the first major step in applying nanophase particles to change the heat transfer performance of conventional fluids. The method followed by Younis et al. [14] was relied upon, and the nanofluids were prepared in two basic steps; The nanoparticles and distilled water are mixed directly as a first step; While an ultrasonic vibrator is used to prepare the mixed aqueous nanofluid as a second step, the appropriate sonication time is also determined to prevent defects appearing on the nanofluids.

## 3. RESULTS AND DISCUSSION

Figure 4 represents the coolant temperature difference between the inlet and outlet of the collector during daylight hours for different concentrations of $Al_2O_3$ Nanofluids. In general, an increase in the ΔT is noticed with an increase in the concentration of nanomaterials when the flow rate is fixed for all nanomaterials additives. At one o'clock, using $Al_2O_3$/water at a mixing ratio of 3% wt. Increase ΔT at 16%, while it decreased by 13% and 11.8% when using 2% and 1% mixing ratios, respectively. The difference in coolant temperature between the inlet and outlet of the collector with a change in the concentration, where the largest difference in the coolant temperature was at a concentration of 3%. This is due to the increase in the heat transfer coefficient of the liquid after increasing the proportion of mixing nanomaterials.




(a) 1.5 l/min

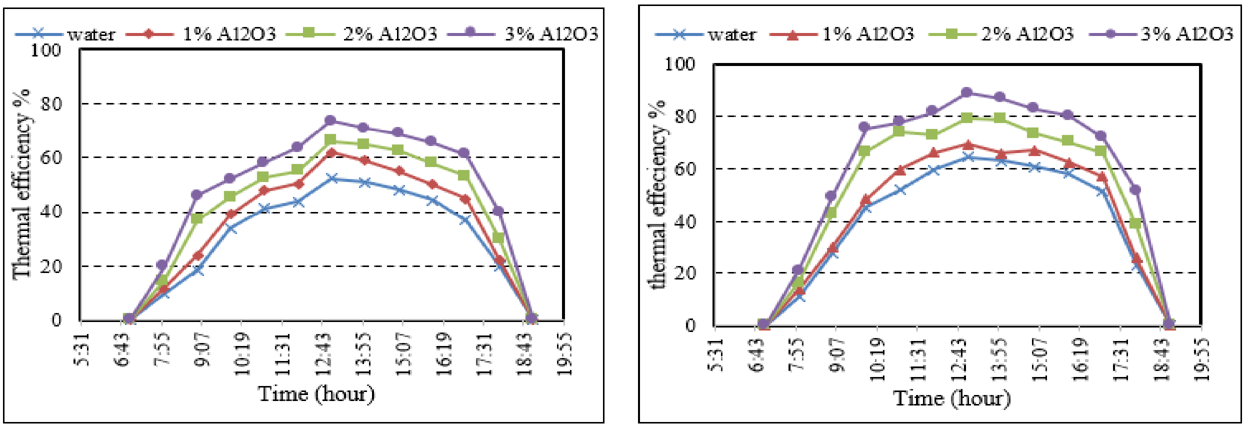



(b) 3.5 l/min

**Figure 4.** Variation of ΔT ($T_{out} - T_{in}$) with time during the day at the flow rate

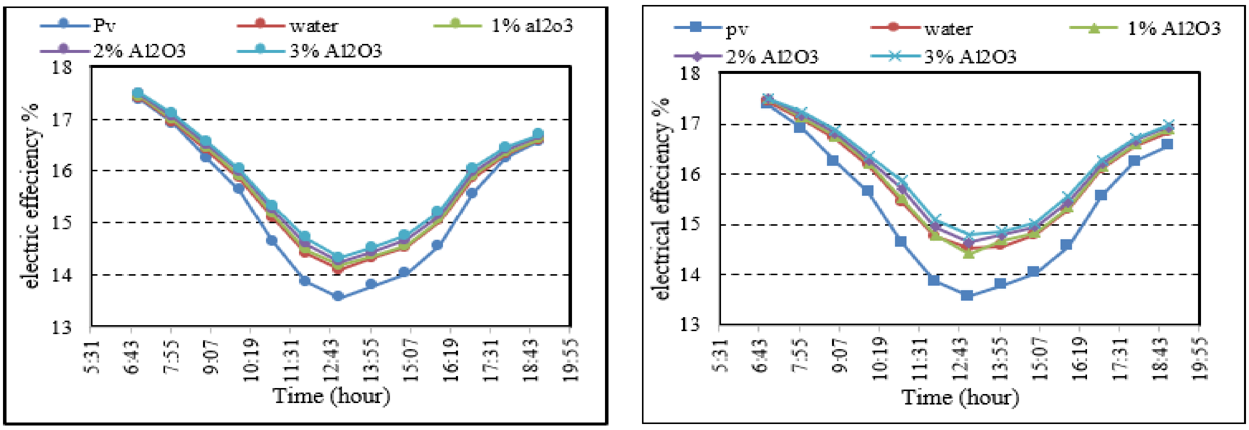
Figure 5 represents thermal efficiency during daylight hours for different concentrations of $Al_2O_3$ nanofluids. In general, we notice an increase in thermal efficiency with an increase in the concentration of $Al_2O_3$ nanomaterial when the flow rate is fixed for both nanomaterials. For example, in the figure at 1:00 pm, using $Al_2O_3$/water at a volumetric concentration of 3% increased thermal efficiency by 18.4%, while it increased by 13.8% and 8.4% when using 2% and 1% concentration, respectively. Also, the flow rate is increased the thermal efficiency increases. The thermal efficiency can be extracted from the results discussed on the PVT unit. This work is like that of Gangadevi et al. [22], where thermal efficiency $\acute{\eta}_{th}$ from 42.46% to 45.60%, as in Younis et al. [14].

Figure 6 represents the electrical efficiency during daylight hours for different concentrations of $Al_2O_3$ nanofluid. In general, we notice an increase in electrical efficiency with an increase in the concentration of nanomaterials when the flow rate is fixed for $Al_2O_3$ nanomaterials. For example, the figure at 1:00 pm notes using $Al_2O_3$/water at a mixing ratio of 3% wt. Increase the electrical efficiency by 12%, while it decreased by 8% and 5.8% when using a 2% and 1% nano additives concentration, respectively. This work is like that of Younis et al. [14]. Electrical efficiency increases from 10.1% to 10.83% with add $Al_2O_3$ nanoparticles in different concentrations from 0.025 to 0.067 kg/sec, as in Gangadevi et al. [22].




(a) 1.5 l/min (b) 3.5 l/min

**Figure 5.** Variation of thermal efficiency with time during




(a) 1.5 l/min (b) 3.5 l/min

**Figure 6.** Variation of electrical efficiency with time during the day at the flow rate

## 4. CONCLUSIONS

Through the use of open-flow flat collector designs, the performance analysis for PV panels was achieved. An investigation of open-flow flat collectors was conducted and analyzed. The following effects were observed as a result of the addition of alumina nanoparticle additives to PV/T systems and PV panels:

- A higher flow rate results in increased thermal energy absorption.
- Utilizing a nanofluid flow rate of 3.5 l/min increased the absorbed thermal energy by 33% compared to 1.5 l/min.
- When $Al_2O_3$/water is mixed at 3% wt., the cell temperature is reduced by 24% compared to the same ratio when using water alone.
- Thermal efficiency increased by 18.4% when $Al_2O_3$ and water nanofluid were used as coolants with mixing ratios of 3% wt.
- An increase in electrical efficiency of 12% was observed when $Al_2O_3$/water nanofluid was used as a coolant with a mixing ratio of 3 wt.% (with a flow rate of 3.5 l/min).

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