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Experimental Study on Photovoltaic Cooling System Integrated with Carbon Nano Fluid

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A B S T R A C T

Nowadays, Because of the sharp decline in fossil resources, producing power by renewable energy is growing rapidly. Photovoltaic (PV) technology is one of the most popular ways for generating electricity. In hot days of year, which the maximum irradiation of sun is available, because of high cell temperature, the efficiency of PV cells is falls down. In this paper, in order to decrease the temperature of PV cells, the use of carbon nano fluid for cooling the PV panel is investigated. The results show that after 4.5 hours of beginning the test, the temperature of PV panel with carbon nano fluid cooling is fixed at 32°C, while the temperature of conventional panel is about 83°C. This temperature difference improved average efficiency around 5.75%. Moreover, in this study, calculation of output power of a 10-KW PV power plant, with and without cooling is performed.

1. Introduction

Due to the intensive decline in fossil fuel reserves, many countries are forced to use of renewable energy sources. One of these sources is solar energy, which can be exploited through photovoltaic panels. By every one degree Celsius growth in temperature of crystalline PV cells, their efficiency will decrease by 0.5% [1, 2]. Several methods have been proposed for resolving this problem. Phase change materials (PCMs) and nano-fluids are the most interesting methods for cooling of PV cells. Vaseline [3], Copper sulphate.5H_2O [4], Capric palmic acid and $CaCl_2$.6H_2O [5], RT40 [6], and RT35 [7] are only a part of materials which tested as PCMs in researches.

Xu and Kleinstreuer [8] developed a two-dimensional model based on CFD for analysing heat, in order to calculate the efficiency of a photovoltaic system. They used nano-fluid in this system and introduced a new thermal conduction model. In addition, they investigated the effect of different components on efficiency and for the system including nano-fluid, showed an increase of 11% in electrical efficiency.

Ghadiri et al. [9] studied the use of ferro-fluid (Fe_3O_4 and water) as nano fluid, in order to cooling photovoltaic panels in an indoor simulated condition. Their results showed an increase of about 45% in electrical efficiency. Furthermore, they indicated that when Fe_3O_4/water was exposed to a magnetic field with a frequency of 50 Hz, the efficiency increasing will reach to 50%. Also, Sardarabadi et al. [10] by mixing deionized water and two different weight percentage of silica for producing nano fluids, reported an efficiency increasing of 7.6% and 12.8% for 1 wt% and 3 wt% of silica nano fluid, respectively. Sugandy et al. [11] performed experiments to compare Zno/Ethylene-Glycol nano fluids and ZnO/Ethylene-Glycol/water to cooling photovoltaic panels. Yousefi et al. [12] studied the use of nano aluminium oxide with water to reduce the temperature of the solar panel. These studies, were carried out with various flow and mass percentage of nanoparticles, indicated that by increasing the flow rate of nano-fluid on the back side of the panel, increase in their efficiency would be occurs. Moreover, review papers on using nano fluids for PV cells has been published by some researchers e.g. Nagarajan et al. [13], Sathe and Dhoble [14] and Mohaghegh [15].

The main aim of this paper is to study the effects of carbon nano fluid as a cheap, Abundant and available substance, on cooling of PV cells. Moreover, a comparison between the output power of with and without carbon nano fluid cooling of 10-KW PV power plant has been done.

2. Nano fluids

2.1. Description

Despite, does not take a long time from nano-science appearance, many scholars have focused their research on this field. nano-technology has been able to effective in various scientific fields. In biotechnology to manipulate DNA properties, nano coatings for various industrial equipment, e.g. gears and bearings to reduce erosion and corrosion caused by the work condition, use in modern sciences such as the nano Electro Mechanical System (NEMS), to increase the storage capacity of hard disks, use in military science, utilization in medicine and pharmacy, etc.

Increasing heat transfer in thermal devices has always been one of the important requirements of industries. One of the most significant properties of nanoparticles, is their great effect on increasing convection heat transfer coefficient (h) in nano fluids. For example, thermal conductivity of copper is about 700 times more than water. So, fluids containing metallic suspended particles, have a higher heat transfer coefficient than pure primary fluid.

Figure 1: Carbon nano particles

2.2. Preparation of nano fluid

The synthesis of nanoparticles is a widespread and growing science. All materials can't be converted to nanoscale by a same method. Each material, according to its physical and chemical characteristics, requires a specific method for transforming into nanoparticle. Complete information on nanoparticle synthesis methods has been explained in [16].

In this study, carbon nano-particles (Figure 1) was used to generate nano fluid. Figure 2, represents the TEM image of carbon. This shape clearly shows that the carbon used has an appropriate diameter in the range of the nano scale. 10 liters of two-times distilled water was used as base fluid. 10 gr of carbon was mixed in distilled water to produce 0.1 wt% carbon nano fluid. After adding carbon particles to distilled water and in order to produce a homogeneous nano fluid, an ultrasonic device was used. Carbon nano fluid was placed in the ultrasonic device for 15 minutes under the frequency of 20 Hz.

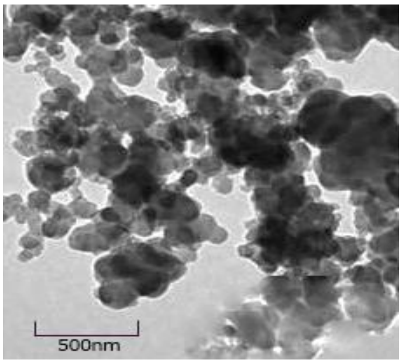

Figure 2: TEM image of nano carbon

3. Experimental set-up

3.1. Description of equipment

The schematic of experimental set-up is As it's clear in this schematic(figure 3), the nano fluid placed at the rear of PV panel, absorbs a part of it heat, and transmitted to heat exchanger to lose this heat and return to rear of PV panel again.

This circulation is continuously repeated until the end of test. Experiment was done for 270 min (4.5 hours). The constant flow rate of 0.5 lit/min was adjusted for circulating. In order to save temperature data, received from data-logger, the numbers of thermal sensors of DS-18B20 type were used. These sensors are water proof and had an accuracy of 0.5°C. This set-up was built and placed in Jundi-Shapur University of technology, Dezful, Iran.

Two similar photovoltaic panels, of Yingli Solar Company have been used. One of them was without any changes and the other one was cooling by nano fluid. Sensors not only measure the temperature of PV panels, but also meas ure the inlet and outlet temperature of nano fluid.

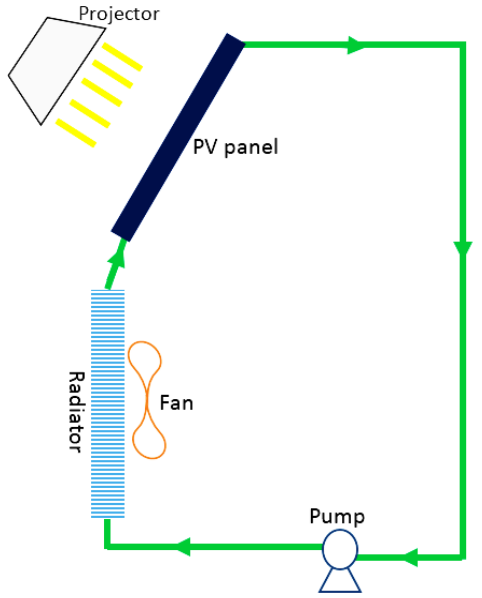

Figure 3. Schematic of experimental set-up

For simulating heat and light of sun, two 1000 W tungsten projectors was used. The projectors had vertical distance of 50 cm to centre of each panel.

The constant irradiation emitted from this distance, was 630 W/m^2 and the PV surface temperature was about 85°C.

3.2. Mathematical formulation

The efficiency of PV panels, is calculated by equation (1):

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{OC} I_{SC} . FF}{A\ G} \quad (1)$$

Where V_{OC} is open-circuit voltage in (V) and I_{SC} is short-circuit current in (A). These parameters are mentioned in table 1, for selected PV panels, according to their catalogue. A is the area of PV cells in (m^2) which in this study is 0.415 m^2 and G is irradiation of sun in (W/m^2).

Finally, the last parameter in equation (1) that should be presented, is Fill Factor (FF) which is defined as:

$$FF = \frac{V_{mp} I_{mp}}{V_{OC} I_{SC}} \quad (2)$$

Where, V_{mp} and I_{mp}, are voltage and current in maximum power, respectively. This parameters are obtained from the data-logger.

As already mentioned, when temperature rises in a silicon based photovoltaic cells, the efficiency of them, falls down. This decreasing in efficiency can be calculated by equation (3):

$$\eta = \eta_0 [1 + \beta (T_{cell} - 25)] \quad (3)$$

Where η_0 is the panel's efficiency in STCs, β is the silicon efficiency temperature coefficient which mentioned in the panel's catalogue by the manufacturer and finally T_{cell} is the cell's temperature under operating condition in Celsius.

Table 1: Electrical characteristics of Yingli Solar 60W PV panel

Module characteristics	Value
Power output (P_{Max}) [W]	60
Module efficiency (η_m) [%]	14.4
Voltage at P_{Max} (V_{mpp}) [V]	18.47
Open-circuit voltage (V_{OC}) [V]	22.86
Current at P_{Max} (I_{mpp}) [A]	3.25
Short-circuit current (I_{SC}) [A]	3.44

4. Results and discussion

In this study, the influence of carbon nano fluid by a constant concentration of 0.1 wt% on electrical characteristics of PV cells, has been investigated. This study was performed in an indoor conditions by constant temperature and light, for 4.5 hours. The results are explained as follows.

4.1. Temperature variation

As shown in figure 4, after about 70 minutes from the start of the experiment, both PV panels reached a constant temperature. From the beginning to the end of experiment, the conventional panel has about 63°C increasing in its temperature. While the carbon nano fluid equipped panel, showed an increase of about 10°C in temperature over the experiment time. In addition, the average temperature difference between panels is about 51°C, which is a significant value.

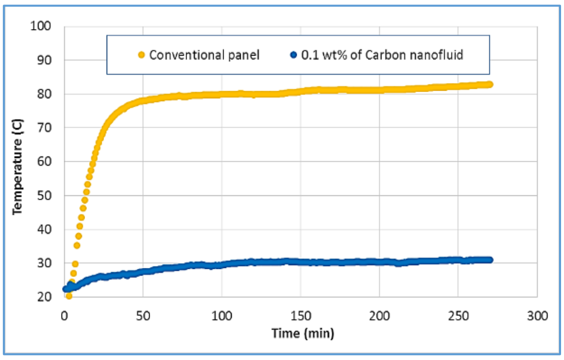

Figure 4: Temperature versus time for both panels

4.2. Efficiency variation

Figure 5, shows the efficiency variations over time. As expected from the results of section 4.1, for temperature variation, the efficiency of the panels has been fixed after about 70 minutes from the beginning of experiment.

The efficiency of the conventional panel, from the 70th minutes until to the end of experiment was between 9.6% to 10.4%, and the panel with carbon nano fluid cooling was also in 15.5% to 16% range. So it can be concluded that the average efficiency difference between these panels was about 5.75%. As it was predictable from the temperature difference, a significant difference in efficiency is seen.

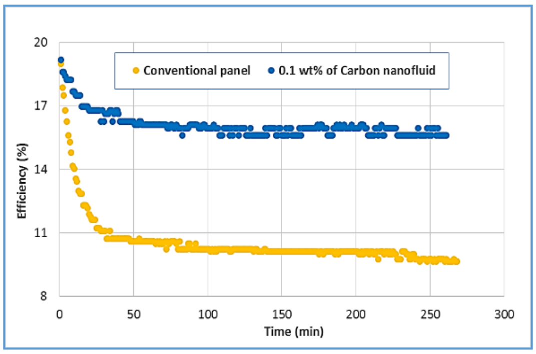

Figure 5. Efficiency versus time for both panels

4.3. Output power

In Figure 6, the diagram of output power has been plotted over time. The output power of conventional panel and also the panel with nano fluid cooling have been fixed at about 30.2 W and 47.2 W, respectively, which is shows a huge difference.

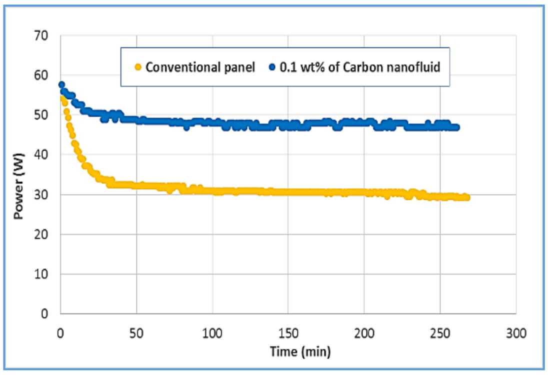

Figure 6: Power versus time for both panels

This difference in output power is better illustrated in figure 7. This figure is a comparison between conventional panel (without cooling) and the panel with carbon nano fluid cooling, for a 10-kW photovoltaic power plant, by considering the mentioned ambient temperature (about 85°C).

As it is clear, the carbon nano fluid power plant, generates much more electricity than the other one.

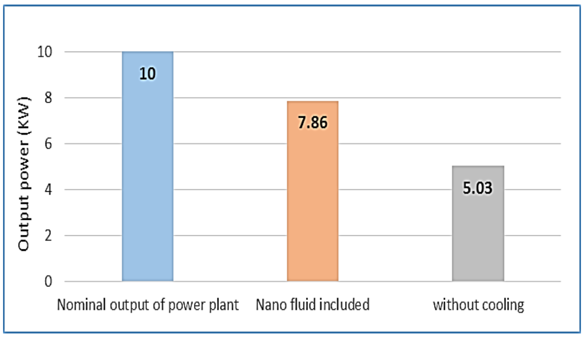

Figure 7: Output power of with and without cooling power plant

As mentioned above, the output power of with and without carbon nano fluid cooling photovoltaic power plant has a significant difference. Here, in order to illustrate the effects of this cooling on required photovoltaic modules, table 2 has been given.

Table 2: The amount of increasing in required PV modules

	Without cooling	With cooling
Increase in required PV modules value (%)	98.80	27.22

The values shown in this table represent the percentage increase in the required photovoltaic modules in two modes of with and without carbon nano fluid cooling, to reach the power of 10 kW. Increase in PV modules require, is also leads to increase in initial cost of a PV power plant.

4.4. Efficiency and temperature dependency

As stated at the beginning of this article, temperature rise in PV cells caused to reduce the efficiency of them.

In order to demonstrate the relationship between temperature and efficiency of this research, figure 8 (a, b) is shown. The slope of this graph is completely in agreement with the results of Tiwari et al. [17], study.

5. Conclusion

In this research, carbon nano fluid was used for cooling photovoltaic panels. The results are summarized as follows:

1-After about 70 minutes from the start of experiment, temperature has been fixed at a constant temperature. The conventional panel reached about 83°C and the panel with a cooling system has temperature of about 32°C. So, temperature difference of about 51°C is seen.

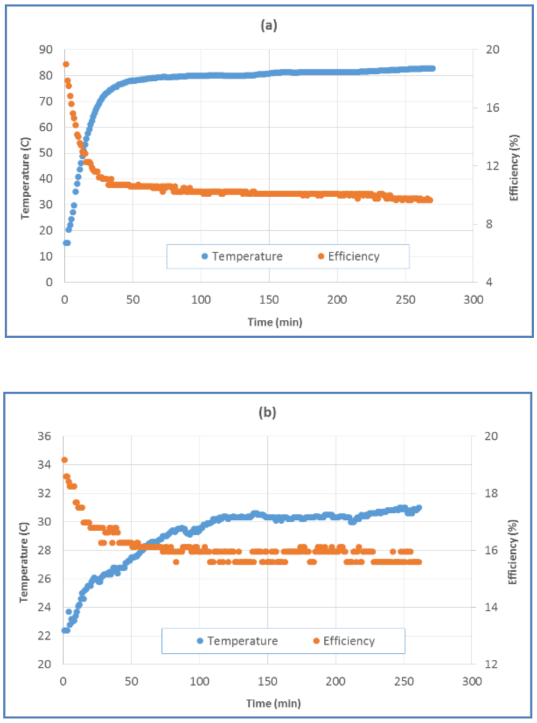

Figure 8: Temperature and efficiency dependency of (a) conventional panel (b) 0.1 wt% carbon nano fluid panel

2-Reduced temperature created by carbon nano fluid circulation, caused to increase of 5.75% in efficiency of PV panels.
3-The output power of a 10 KW photovoltaic power plant without cooling is reduced to about 5.03 kW. While, by carbon nano fluid cooling with mentioned details, the output power of this power plant is reduced to 7.83 KW.
4-Temperature and efficiency dependency is also shown for the condition of this study.

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Nomenclature

η	Efficiency (%)
P	Power (W)
V	Voltage (V)
I	Current (A)
A	Area (m^2)
G	Solar irradiation (W/m^2)
β	Silicon efficiency temperature coefficient
T	Temperature (°C)
FF	Fill Factor
Subscripts	
Max	Maximum
OC	Open circuit
SC	Short circuit
mp	Maximum power
cell	Photovoltaic cell
out	Output
in	Input

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