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Experimental Investigation of Cooling Performance Enhancement of a Photovoltaic Module Using a Phase Change Material-CuO Nanoparticles

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ABSTRACT: In this work, the effect of using the mixture of a phase change material and CuO nanoparticles as a cooling agent on the performance of a photovoltaic module has been investigated experimentally. The phase change material located in a chamber at the backside of the module is cooled with spiral copper tubes. Phase change material due to absorbing a lot of heat from the surface of the module and control the heat capacitance of the system causes to raising its overall efficiency. The effect of CuO nanoparticles concentration (0.5-4% wt.) and the weight of phase change material (1-2.25 kg) on the different parameters such as the surface temperature of the photovoltaic module, increase in maximum power and cooling efficiency have been investigated. Results show that using pure phase change material significantly causes to decrease in the surface temperature of the module from 58.34 ºC to 51.7 ºC. In addition, data depicted that adding CuO nanoparticles to the pure phase change material results in increasing the cooling efficiency and the produced power. Increasing the weight of pure phase change material and the mixture of phase change material -4% CuO from 1 kg to 2.25 kg results in a decrease in the surface temperature of the photovoltaic module from 51.7 ºC to 48.1 ºC and 45 ºC to 42.9 ºC, respectively. In addition, by increasing the nanoparticles in phase change material, cooling efficiency and the produced power are increased and the highest values are 22.87% and 3.46 W attributed to the layout of using 2.25 kg phase change material and 4% CuO.

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1. INTRODUCTION

Solar energy is considered as one of the renewable energy sources that is always available and does not produce any specific waste [1-3]. The demand for cheap and abundant energy has increased the use of Photovoltaic (PV) systems to generate electricity through solar radiation. There is a direct relationship between the conversion of solar energy to electricity and the surface temperature of photovoltaic modules and maximum efficiency is between 14-17% [4]. The efficiency of PV modules 0.5% decreases per 1°C increase in their surface temperature. Therefore, finding efficient methods for cooling the PV modules in order to remove the high amount of heat from their surface is seriously needed. Some active and passive new methods have been used to enhance the cooling performance of PV modules. Active cooling techniques have high efficiency and lead to high amounts of energy. Passive cooling techniques are divided into three main groups, including passive cooling of the air, passive cooling of the water and conductive cooling. A particular type of passive conductive cooling in PV modules is the use of Phase Change Material (PCM), which has been considered by many authors. PCMs due to their high ability to get plenty of surface temperature of PV modules, help to control the thermal capacity of the system to increase their efficiency [1]. In this study, the effect of using PCM and CuO nanoparticles as a cooling agent on the cooling performance of a PV system has been studied experimentally. Indeed, the innovation of this study is the simultaneous use of CuO nanoparticles and PCM material to cool a photovoltaic module, in which the PCM is cooled by cold water flowing in the spiral copper pipes. In this paper, copper oxide nanoparticles have been added to PCM because of its high thermal conductivity coefficient. In general, the effect of concentration of CuO nanoparticles (0.5-4%wt) and weight of PCM (1.2-25 kg) on different parameters such as module surface temperature, maximum power increase and cooling efficiency of the PV modulus are investigated.

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2. EXPERIMENTAL SETUP AND EXPERIMENT PROCEDURES

An experimental setup is built to investigate the effect of PCMs on the efficiency of a PV system. The basic components of the setup used in the present work are consisting of a PV module, a solar simulator, and a reservoir and a data acquisition system. In order to measure the temperature, 9 thermocouples are attached on the surface of the PV module, with an extremely thin layer of a thermal epoxy. A thermometer (Lutron, BTM-4208SD) and an electrical load system connected to the PV electrical output are used to measure and record the data. During the experiments, the electrical load is used to measure PV voltage at different demanded electrical current. The PCM located in a chamber at the backside of the PV module is cooled with copper microchannel tubes. In order to cool the PCM, copper channel tubes in which cold water is flowing have been used. The schematic of the cross-section of the PV module and the copper tubes surrounded by PCM-CuO nanoparticles can be seen in Fig. 1.

A solar simulator is fabricated and used to imitate the necessary solar irradiation in the experiment of photovoltaic modules section. In the present study, CuO nanopowder with a diameter of <50 nm (purity, 99.5 %) is supplied by Sigma-Aldrich Company. The density and surface area of CuO nanoparticles are 6300 kg/m^3 and 29m^2/g, respectively. Nanoparticles of CuO are used because of their specific characteristics and high electrical conductivity. The paraffin wax has been used as PCM is supplied by Haya Chemical Company (HCC) in Iran. All the experiments are performed at room temperature (16-17°C).

3. RESULTS AND DISCUSSION

Initially, experiments were performed for the non-cooling system and all data were recorded, including module temperature, voltage, and current. The temperature at most points of the PV module is maintained at approximately 60 minutes reach steady condition and the maximum average temperature for after minute was about 58.4 ºC. In the next step, 1 kg of pure PCM was poured inside the chamber behind the PV module and experiments were repeated to verify the effect of the pure PCM on reducing the surface temperature of the PV module. The experiments were repeated at different concentrations of PCM and CuO nanoparticles. Fig. 2 shows

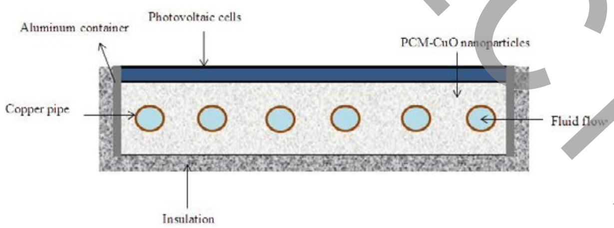

Fig. 1: The schematic of the cross-section of the PV module and the copper tubes surrounded by PCM-CuO nanoparticles.

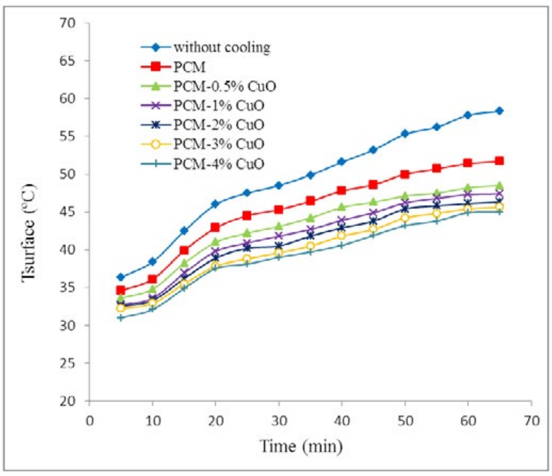

Fig. 2: Variation of the average temperature of the PV module with time for the non-cooling system, using PCM and simultaneous use of PCM and nanoparticles (Q = 1 L/min, W = 1 kg).

the average temperature variation of the PV modules in the three mentioned states. This figure shows that in the absence of a cooling system, the surface temperature of the PV module was steadily increasing and reached to about 58°C approximately after 65 minutes. However, with regard to the use of pure PCM and the combination of PCM and CuO nanoparticles, the surface temperature of the module decreased significantly and the slope of the temperature increase decreased. After 60 minutes, the surface temperature of the PV module for all three cases was constant and the system was stable.

The reason for the temperature reduction of the PV module surface by using PCM is the absorption of additional heat from its surface by phase change material. In addition, as shown in Fig. 2, with increasing concentration of CuO nanoparticles, the surface temperature of the PV module is reduced and the best condition is related to the combination of PCM and CuO% 4, which temperature reached to 45 °C. The presence of copper oxide nanoparticles in the phase change material leads to an increase in its thermal conductivity and increases the absorption capacity of the heat. The effect of PCM weight (W=1-2.5 kg) and PCM-% 4CuO nanoparticles was investigated. Initially, by changing W from 1 kg to 1.5 kg, the surface temperature of the PV module decreased with steep gradients and the slope of the temperature changes for W=2 kg is decreased. However, no significant temperature changes for W=2 kg and W=2.5 kg are found, which means that the W=2 kg for both states has a high ability to absorb the heating surface of the PV module. The results showed that increasing the water flow rate caused a decrease in the surface temperature of the PV module. The power output of the PV modules for the PCM+ CuO nanoparticles with different concentrations and for different weights of paraffin wax was investigated. These results show that increasing the concentration of CuO nanoparticles in PCM and increasing the PCM weight leads to an increase in its cooling performance and, as a result, the surface temperature of the PV modules decreases.

4. CONCLUSIONS

In this paper, PCM material is used to cool and reduce the surface temperature of a photovoltaic module. In order to postpone the melting of the PCM material, the copper spiral tubes are placed with a slight distance under the surface of the PV module within the PCM material in the backside of the module and cool water flows from them. The addition of nanoparticles to the PCM leads to an increase in the thermal conductivity and its ability to absorb heat from the PV surface and a decrease in the surface temperature of the PV module. The effect of nanoparticle concentration and PCM weight on different parameters such as module surface temperature, maximum power increase and cooling efficiency of the PV module were investigated. According to the results, the use of pure PCM and the combination of PCM and CuO nanoparticles leads to a decrease in the surface temperature of the module and increase the cooling efficiency and also power output of the photovoltaic module.

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