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Comparative study to use nano-(Al_2O_3, CuO, and SiC) with water to enhance photovoltaic thermal PV/T collectors

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ABSTRACT

The reduction in efficiency of photovoltaic (PV) units due to increases in cell temperature occurs when a small part of the absorbed solar radiation is converted into electricity and the remaining part is lost as heat. Recently, the addition of a range of nanomaterials with high thermal conductivity to the cooling fluid in PV/T systems has been the subject of much research. In this study, three nanomaterials were added to water as a base fluid with several volume fractions to determine the best concentration and nanoparticle for this application. The PV/T system was setup in an indoor laboratory. Knowing which material has a better effect on the PV unit in particular, and the PV/T unit in general, is important for deciding which nanomaterial is more suitable for the system. The results reveal that nanofluid gives higher thermal conductivity with very little increase in the fluid density and viscosity compared with the base fluid. The studied volume fractions were 0.5, 1, 2, 3, and 4% and the selected nanoparticles were Al_2O_3, CuO, and SiC. It was found that silicon carbide nanoparticles have the best stability and the highest thermal conductivity compared to the other two nano-substances. Copper oxide nanofluid has higher thermal conductivity than aluminium oxide but lower stability, although it was found here that this material reliably stable compared to in other studies. The nanofluid reduced the indoor PV/T system temperature and enhanced its generated power.

1. Introduction

The use of nanofluids in solar heat exchangers is a recently developed way to improve heat transfer properties. Moreover, adding nanomaterial to conventional heat transfer fluids improves their thermal properties [1]. The use of nanofluids in solar heat exchangers has attracted considerable attention by researchers recently due to the significant improvement in heat transfer compared to conventional fluids [2].

Maxwell [3] first noted that the addition of solid particles to conventional heat transfer fluids enhances their thermal conductivity. However, dispersion is problematic for solid particles in liquids as they accumulate, leading to their sedimentation. This causes a consequent blockage of flow paths, corrosion of flow pipes walls, and an increased pressure drop. In 1993, study by Masuda et al. [4] indicated that a combination of micrometre size solid particles and conventional heat transfer fluids could enhance thermal conductivity. However, researchers have encountered the problem of the deposition of particles at the base of the liquid's container, which reduces the utility of thermal conductivity. In a later study, Choi [5] managed to prepare liquids containing nanometre-sized materials. He observed a significant improvement in the thermal conductivity of the resulting fluid. Moreover, the dispersion of nanometre-sized particles in conventional liquids was sufficient and resulted in stability and a suspension without precipitation. The benefits of using nanomaterials in fluids come from the fact that they provide a higher surface area than that of conventional fluids. Many researchers have studied the benefits of adding these nanomaterials to fluids and applications that can take advantage of the enhancement in heat transfer, especially solar collectors. Table 1 lists some of these studies.

Table 1 shows some of the experimental and numerical works conducted on the thermal behaviour of different types of nanoparticles operating in applications with heat exchangers of different geometries. For the interested reader, many review papers have highlighted this work in detail [16–20].

Photovoltaic cells (PV) are made of semiconductor materials which produce electricity by converting sunlight radiation which

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Table 1
Studies on the use of nanomaterials to enhance the thermal conductivity of the base fluid (water).

Ref.	The used nanomaterial	The base fluid	Thermal conductivity enhancement rate (%)	Notes
Li and Xuan [6]	Cu	Water	60	The study focused on convective heat transfer enhancement when Cu-water nanofluid is used
Wen and Ding [7]	Al_2O_3	Water	30	Experimental work conducted using Al_2O_3-water nanofluid in copper tubes. Considerable enhancement was observed with nanofluid use especially at the tube entrance
He et al. [8]	TiO_2	Water	26	Several nanoparticles of TiO2 in size and concentrations were used in water. It has been found that the resulting solution is stable and has higher thermal conductivity
Hwang et al. [9]	Al_2O_3	Water	8	Al_2O_3 nanoparticles were added to water to transfer heat in a flow of a circular tube system that is a uniformly heated. The convection heat transfer coefficient and pressure reduction were measured during the system run in the case of laminar flow. The convection heat transfer coefficient was increased to 8% with 0.3% nano-concentration
Chandrasekar and Suresh [10]	Al_2O_3	Water	60	An experimental study was conducted to observe the heat transfer properties of Al_2O_3-water nanofluid. The results indicated an enhancement in Nusselt No. which was due to the physical thermal properties of nanostructures
Yousefi et al. [11]	Al_2O_3	Water	28.3	Experimental work used flat plate solar collector
Rayatzadeh et al. [12]	TiO_2	Water	65	The experimental investigation was conducted to evaluate the effect of using continuous induced ultrasound in the formation of nanofluid under continuous heat flow. The study showed that the addition of TiO_2 nanoparticles to water enhances the Nusselt No., and increasing the nanoparticle concentration has led to further improvements in this number
Nimmagadda and Venkatasubbaiah [13]	TiO_2 Ag	Water	43	This study investigated the properties of heat transfer flow when a micro-channel system working with nano (Al_2O_3), Ag, and hybrid (Al_2O_3 + Ag). The study showed a significant enhancement of heat transfer properties when using these nanomaterials
Bajestan et al. [14]	TiO_2	Water	21	Practical experiments and numerical modeling study was conducted to evaluate the improvement in the heat transfer coefficient of laminar flow when adding titanium dioxide nanotubes to the water flowing through a tube that is heated uniformly
Adriana [15]	Al_2O_3, TiO_2 and SiO_2	Water	12	The thermodynamic properties of nanomaterials were studied to determine the behaviour of heat transfer and the numerical evaluation of three nano-oxides that were suggested. The study observed that the properties of studied nanoparticles, whether physical or thermal, varied with the concentration of nanoparticles in the fluid

stimulates electrons. As only a fraction of the solar spectrum is utilized in this process to excite electrons to create electron-hole pairs, the photovoltaic cells have limited electrical efficiency. Photovoltaic cells mainly absorb the solar spectrum between 700 nm and 1100 nm. Shorter or longer wavelengths are not collected [21,22] but converted to heat that can reduce cell efficiency or, to some extent, cause damage [23].

In contrast, solar thermal energy collectors (consisting of a heat transfer fluid inside a tube or container with a solid surface that absorbs heat) can utilize the entire solar spectrum [24]. In recent years, nanofluids have been explored as more efficient cooling liquids than air and water. This property was applied to cool PV cells and was referred to as a hybrid thermal photoelectric cell [25]. Many studies have shown that hybrid PV/T is more efficient than individual photovoltaic or thermal systems because it benefits from most of the incident solar energy [26,27]. The low temperature of the photovoltaic cell increases its output capacity and the heat absorbed by the solar collector can be used in other applications. Table 2 summarizes some of the recent works in this field.

As Table 2 indicates, there are major achievements in the field of employing nanoparticles to cool down PV/T systems, but as many researchers have pointed out, there are still many aspects under discussion such as thermal absorber design, materials used, coating, cost minimization, conservation of energy, performance testing and control. Research is under way to overcome the difficulties associated with the use of nanofluids in PV/T systems.

In this investigation, three types of nanoparticles will be studied. These nanoparticles were chosen from a group of species that had two important properties, namely high thermal conductivity and moderate prices. Also, these materials have been used in previous research works dealing with PV/T systems, which give an important comparison of all properties studied with previous literature. For example, Al_2O_3 was investigated in Refs. [7,9,10]; Refs. [43–45] studied the use of CuO, and SiC was investigated in Refs. [47,48,50]. Since the size of the system used is 12 l, the amount of nanoparticles used was 0.2717 kg of CuO, 0.14 kg for alumina, and 0.1592 kg of silicon carbide. These quantities have reasonable prices in the local markets all over the word (1 US dollar/g) which confirm the good selection if these materials. Nanoparticles will be used to form nanofluids with water and the resulting fluid cooling efficiency will be evaluated in an indoor PV/T system using a solar simulator to control the solar intensity variation. The aim of the current study is to determine which ratios are more suitable for mixing nanomaterials with water with regard to thermophysical properties, the maximum output of electrical and thermal energies and efficiency.

2. Experimental setup

2.1. The indoor PV/T simulator

A thermal solar energy basic unit "MINI-EESTC", made in Italy, was used as an indoor solar simulator. The rig consists of a solar collector made of tempered glass whose surface was replaced by a copper plate to operate as a heat transfer agent. A PV panel is placed above the upper plate, whose specifications are listed in Table 3. The back of the panel and the top plate surfaces were painted with silicone oil to avoid any air gaps that may reduce the heat transfer from the panel to the collector. Inside the collector, there is a copper pipe mesh welded to a copper plate to increase the heat transfer rate. Above of the photovoltaic cell there are fifteen bright lights installed to provide variable intensity of 0–1500 W/m^2 controlled by the control panel as a solar simulator. This simulator has a fluid circulating pump that gives options to operate the system in forced or natural convection. However, in this study, the natural convection heat transfer mode was used. When the PV panel is heated, it transfers its accumulated heat to the collector causing the temperature of the working fluid inside to increase. Water movement can be achieved by natural convection due to the difference in temperature between the cold fluid in the tank and hot fluid in the collector or by using a pump (forced