The possibilities of using nano-CuO as coolants for PVT system: An experimental study

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Abstract. Photovoltaic/thermal system (PVT) is a modern technology that increase the productivity of a PV panel through nanofluid cooling. In this study, the use of a group of nano-coolants consisting of nano-CuO plus water and surfactant was investigated. The study was conducted using a solar simulator and studied the thermophysical properties of the prepared fluids to demonstrate their effects on the PVT system cooling. Adding nanoparticles to water caused an increase in density and viscosity, but at a limited rate, and it did not have an effect during the experiments. The thermal conductivity of the nanofluids showed a clear increase compared to water, and the highest conductivity measured was 100.3% (when adding 2% nano-CuO). The Zeta potential test was used to measure the stability of the prepared nanofluids, and the results showed the high stability of all the prepared nanofluids. The stability of the suspension improved as the proportion of added nanoparticles decreased. The electrical, thermal, and total efficiencies improved with employing nanofluids to cool the PVT system compared to cooling with water alone. The maximum efficiencies obtained when adding 2% nano-CuO to the water were 29.92%, 61.08%, and 91% for electrical, thermal, and total efficiencies respectively.

1. Introduction

In 2018, the increase in carbon emissions resulting from power generation increased globally by 1.7%, which was considered a record-breaking impact of the annual increase in energy demand by 2.3% [1]. The fossil fuels consumption for energy production is the greatest challenges facing humanity due to the severe environmental consequences such as air pollution and global warming resulting from this use. Iraq, as a country that consumes large quantities of fossil fuels in generating electricity and transportation, its environment and air has become heavily polluted [2]. The shift towards producing clean and environmentally friendly electricity using renewable energy technologies is an important way to reduce the impact of pollution. Several proposals have been submitted to confront the dilemma of high energy demand, and the most important of these proposals is a shift towards the use of environmentally friendly green renewable energies. Solar energy is a renewable energy and it is available around the world on a daily basis and can be used completely safely to produce electricity...
and heat. Iraq enjoys great solar brightness throughout the year and high radiation intensity as it is close to the range of the sun belt. Photovoltaic is one of the successful applications of solar energy. PV modules are made of semiconductors, which convert the solar radiation to electricity. The fault of these cells is that a large part of the received solar energy is converted into heat and a smaller part is used to generate electricity. When the PV module temperature increases, the output voltage decreases, causing a decrease in the electrical capacity generated [3]. Ref. [4] shows that the electrical power generated by the photovoltaic cell reduces by 0.45% for every 1°C rise in the PV temperature (more than 25°C). Also, this increase in temperature may result in the formation of thermal pressures that cause damage to the solar cells or a significant reduction in their life span in the long term [5]. Several researchers have suggested preventing or reducing this negative effect of increasing the PV temperature by distracting heat from these cells. Several different coolants have been introduced for this purpose such as air [6], water [7], nanofluid [8], phase-change material [9], and phase-change material and nanofluid [10]. The passage of a liquid attaching the PV modules back absorbs significant amount of heat from the PV and then transfers it to another application in order to achieve a reduction in the PV panel’s surface temperature and a clear improvement in the power generated [11]. This technology is called PVT systems.

The nanofluids used as a coolant was launched in 1995, and until today, thousands scientific researches have paid efforts to study nanofluids and their role in improving heat transfer [12, 13], and the possibility of using them in renewable and sustainable energy systems [14], especially the solar collectors [15, 16]. Adding nanoparticles to the base fluid (water or ethylene glycol and others) results in a change and improvement in the thermal conductivity due to the resulting nanofluid compared to the base fluid [17]. Ref. [18] demonstrated the potential of thermal conductivity enhancing by using a suspension of MWCNTs + Water nanofluid by more than 33%. While Ref. [19] considered that the three carbonate salts (Na2CO3-Li2CO3-K2CO3) with nano-SiO2 (that have diameters from 5 to 30 nm) when added to water cause an enhancement in the PVT system specific heat capacity up to 116.8%. Ref. [20] focused on the influence of the amount of added nanoparticles on the resulting nanofluid thermal conductivity. For this purpose, nano-Al2O3 was used, which was added to the water (fluid base). The study concluded that there is a fundamental connection between increasing the concentration of nanoparticles with increasing pumping power and the presence of thermal resistances inside the used exchanger. Ref. [21] focused on the base fluid type impact on the thermophysical specifications of the nanofluids. The researchers studied three types of nanoscale liquids (water, water + 35% ethylene glycol and water + 35% propylene glycol), and nano-silicon carbide (SiC) was added to them with different mass fractions. The results showed a clear increase in the nanofluids’ density and viscosity depending on the added nanoparticles fraction, while the viscosity of water + propylene glycol had the maximum value compared to the rest nanofluids. As for the studied nanofluids’ thermal conductivity, they were close within the range of temperature studied.

Ref. [22] studied two different types of nanofluids (water + nano-Ag and water + nano-Al2O3) influence on a PVT system performance. The study concluded that increasing the concentration of nanoparticles in the suspension caused the thermal conductivity to be increased. Besides, the thermal conductivity increments of (water + nano-Ag) were more than that of the second nanofluid because of the characteristic properties of nano-Ag, such as high surface area, and high surface-to-volume ratio. Ref. [23] investigated influence of the type of heat exchanger used in the PVT system cooled with nanofluid (water + magnetite) on the system total performance. The studied collectors are the serpentine tube and plate collector, replacing a normal serpentine tube with a 3-rib serpentine tube and using a 6-rib tube. The study showed that the PVT system with 6 ribs gave the best results compared to the rest of the systems (a 3.8% increase in energy efficiency). Ref. [24] stated that the heat transfer efficiency of a nanofluid with a high thermal conductivity that flows laminated is higher than that of its turbulent flow in PVT systems. The diameter of the nanoparticle also has an effect on this result, as nanofluids that have nanoparticles with larger diameters the heat transfer efficiency increases in turbulent flow while just the opposite is true for the laminar flow condition. The study showed that the circulating of nanofluids in the PVT systems can stop the thermal stress in photovoltaics.

Researchers have proposed several ways benefit from the heat removed from the PVT system by using nanofluids, such as in low-temperature applications (heating crops and agricultural drying, heating
water for domestic purposes, industrial preheating, and space heating for comfort purposes) [25, 26]. Other researchers suggested using the heat obtained from the PVT systems to heat solar distillate water and increase distillers’ productivity [27, 28]. To date, there is no agreement on a specific nanoparticle as an additive to water to form an ideal nanofluid, and R&D research is still ongoing to find the best nanofluids used in PVT systems. Within this endeavor, this study examines the possibility of using a nanofluid (water + nano copper oxide) in the PVT system and the extent of improvement in the performance of this system.

2. Experimental Setup

2.1 Internal PVT simulator

The current study was done indoor using a solar simulator type "MINI-EESTC", made in Italy. Two photoelectric panels were used in the experiments (the specifications of which are listed in Table 1). As for the PVT system, it consists of a photovoltaic panel and its back surface has been substituted by a copper plate to facilitate the transfer of heat from the cell to the nanofluid tubes. A copper tube mesh is welded to increase the heat transfer rate. The simulator contains fifteen lamps that can provide a variable radiation intensity ranging from 0 to 1500 watts/m². The PVT system has been connected to a pump to circulate the nanofluid, and it works with operating and speed-up capabilities to generate forced or natural convection. Figure 1 depicts a picture of the solar simulator system. Five thermocouples are installed to measure the temperature (room temperature; PV cell surface temperature, PV cell back temperature, incoming coolant temperature, and exiting coolant temperature). The simulator provides full coverage on four sides of the solar panel (three sides of the collector are surrounded aluminium curtains while the last side is locked by the cooling tank).

![Figure 1. Solar simulator schematic diagram showing the main PVT system components, which are (i) PVT collector, (ii) Water tank, (iii) inlet/outlet water pipes, (iv) measuring devices, (v) water pump, and (vi) solar simulator.](image-url)

### Table 1. The PV panel properties

| PV panel property                      | Specification         |
|----------------------------------------|-----------------------|
| PV panel type                          | APM-P 110-12          |
| PV panel dimensions                    | 1450 mm x 450 mm x 35 mm |
| PV operating temperature range         | From -40°C to 90°C    |
| PV open circuit voltage                | 21.6 V                |
| PV short circuit current               | 7 amp                 |
| PV panel weight                        | 11.4 kg               |
| Voltage at maximum power               | 17.2                  |
2.2 Nanofluid preparation

The mixing of nanoparticles with the base fluid is critical in determining the stability and thermophysical properties of the resulting suspension. For this study, nano-copper oxide (nano-CuO) was added to the water with the addition of a small amount of surfactant (cetyl-trichromyl ammonium bromide) depending on Ref. [17] results. The selected nanoparticles have a high purity of 99%, a small particle size from 35 nm to 45 nm, and a high thermal conductivity of 32.9 W/m K. The color of these particles is black, so once mixed with water the mixture turns black. These article are available in the local market with medium price.

An analytical balance type “EJ610-E” employed to weight Nano-copper oxide and then added to water in a TELSONIC ULTRASONICS CT-I2 tank at intervals and then a surfactant was added. The tank was left to vibrate continuously for 3.5 hours, depending on the results of Ref. [29], in order not to allow agglomeration of nanoparticles. Four nanofluids were prepared by adding nano-CuO in weight ratios of (0.5, 1.0, 1.5, and 2%). After mixing each type of studied nanofluids, samples are taken and stored in a glass container. These samples are subjected to thermophysical properties easements, as well as stability checks, which were done every week, for 10 weeks.

2.3 Prepared nanofluids properties measurements

The studied nanofluids properties were measured using the following:
1. The studied fluids density was measured by weighing a sample of constant volume (150 ml).
2. The studied fluids viscosity was measured using Brookfield programmable nanofluid viscosity meter (model: “LVDV-III highly programmable”) was used. This meter is connected to a personal computer in which data is collected and stored.
3. The studied fluids thermal conductivity was measured using “HOT DESK Tps 500” thermal conductivity meter “KJUTALEY, Sweden”. The device was calibrated with accuracy of over 98.7%.

2.4 Experimental procedures

After mixing the nanoparticles and preparing the nanofluids, their thermophysical properties and the stability of the mixture are examined, in order to explore the best nanofluid that can be used to cool a photoelectric cell in a PV/T system. In the second part of the experiments, experiments are conducted on the PV/T system installed in the solar simulator. The first set of experiences was done employing water as a coolant to be considered as a reference in comparison with the nanofluid. Then the selected nanofluid is used to cool the system and its effects were analyzed for the overall system performance. In this study, the intensity of natural solar energy is simulated, which changes with time. Experiments start at 7 am with an intensity of 250 W/m², and this intensity is increased by 150 W/m² every hour from 7 am until 12 pm. The lighting intensity is fixed for the period from 12 am to 2 pm at 1000 W/m², then it begins to decrease by 200 W/m² every hour up to 6 pm. The aim of the current study is to assess the possibility of using nano-CuO in the cooling of PV/T systems under laboratory conditions of high irradiance. The study also focused on finding the best mixing ratio between water and nanoparticles, which can provide the best output for the PV/T system.

3. Results and Discussions

The thermophysical properties of the prepared nanofluids are listed in Table 2.

| Nanofluid type | Volume fraction (%) | Thermal conductivity (W/m K) | Density (g/cm³) | Viscosity (mPa·s) | Zeta potential (mV) |
|----------------|---------------------|-----------------------------|----------------|------------------|-------------------|
| CuO (%)       | 0.5                 | 0.74                        | 1.0012         | 1.011            | 67                |
| CuO (%)       | 1.0                 | 0.93                        | 1.0031         | 1.02             | 63                |
| CuO (%)       | 1.5                 | 1.11                        | 1.0040         | 1.0215           | 58                |
| CuO (%)       | 2.0                 | 1.22                        | 1.0052         | 1.022            | 49                |
3.1 Thermal conductivity

Thermal conductivity expresses the heat transfer potential of a substance [30]. A great interest in nanofluids has arisen due to their high thermal conductivity relative to the basic fluid. The thermal conductivity of nanofluids depends on the type of nanoparticles added, the concentration of these particles, as well as their shape and size [31]. Other factors such as the type of base fluid are also involved in determining the thermal conductivity [32]. The thermal conductivity in Table 2 shows a clear increase in the conductivity of the nanofluid with an increase in the amount of nano-CuO added. Conductivity increased by 23.33% when adding 0.5% nano-CuO compared to water. The thermal conductivity also continued to increase with the increase in the amount of nano-CuO added reaching 100.3% upon adding 2% of nano-CuO.

3.2 Density

The high fluid density causes a decrease in the pumping pressure and the need for higher pressures to reach an appropriate circulation speed, which results in negative effects on heat transfer [33]. The results of the density measurements listed in Table 2 show an increase in density upon increasing the amount of nanoparticles added. The increase in density was very limited, as it did not exceed 0.051% when adding 2% nano-CuO.

3.3 Viscosity

The viscosity of the nanofluid must be considered when choosing to act as a coolant in PVT applications in addition to its high thermal conductivity [34]. Viscosity is an important temperature-dependent property that has a major role in the thermal conductivity of fluids, as it expresses the resistance to fluid flow through system pipelines. Nanofluids have a higher viscosity than the primary fluid [35]. As a result, the viscosity affects the energy the system needs to circulate the nanofluid, and an increase in viscosity means a higher pumping force is needed [36]. The viscosity measurements listed in Table 2 show that the viscosity of the nanofluid increases with the increase in the mass of the added nano-CuO. The highest viscosity was when adding 2% of nano-CuO to the water, as the percentage of increase was 2.2%.

3.4 Nanofluid stability

The stability of the nanofluid is an important characteristic, as it means that the nanoparticles remain suspended in the base fluid without aggregating and depositing, which affects the nanofluids high conductivity. The zeta potential analysis was used to measure the stability of the fitted nanofluids. The change in the behavior of free electric charges in the base fluid that is attracted to the opposite nanoparticles on the surface of the suspended nanoparticles is measured here. The stability of a nanofluid is considered excellent if its zeta potential is greater than ± 60 mV. In the case of zeta potential of the nanofluid between 40 and 60 mV, the stability of this fluid is considered very good. In the case of a measured zeta potential between ± 30 to 40 mV, this nanofluid is considered to be rather stable. In the case of zeta potential less than ± 30 mV, the examined nanofluid is considered unstable. Zeta voltage measurements in Table 2 show that adding nano-CuO at 0.5% and 1% has high stability due to its high zeta potential. This result was based on the use of nano-CuO with a high surface area. The zeta voltage reached 58 mV when adding 1.5% of nano-CuO to the water and this suspension is considered to have very good stability. Zeta voltage reached 49 mV when adding 2% of nano-CuO, and this scale means that the suspension has good stability.

3.5 PVT system performance

The use of coolant fluids aims to get rid of the excess heat, which reduces the voltage produced by the cell and thus improves the performance of this cell. Figure 2 shows the effect of the intensity of the incident radiation on the photovoltaic panel on the temperatures of the tested coolants for the PV/T system. The increase in the radiation intensity causes a clear increase in the water temperature, while when using the nanofluids, the temperature of the circulating fluids decreases due to the heat transfer and disposal in the tank. The temperatures of the nanofluids with the highest thermal conductivity (2%
Nano-CuO) decreased more than the rest of the tested fluids. The constant drawing of heat from the PV panel improves its productivity. Ref. [37] manifested that the generated voltage is highly affected by increasing the temperature of the photovoltaic cell, unlike the current, which is relatively limited affected. Figure 3 shows that the circulation of nano-coolants in a PVT system caused a significant improvement in the power produced by the photovoltaic panel as a result of cooling. The results show that using 2% nano-CuO is the best liquid to cool the used PVT system, as the improvement in the generated power reached 34.25% compared to water for a full-day operation.

**Figure 2.** The effect of radiation intensity on coolants temperatures

![Figure 2](image2)

**Figure 3.** The effect of radiation intensity on generated power

![Figure 3](image3)
Figure 4 shows the effect of nanofluid circulation on the electrical efficiency of the tested PVT system. The increased radiation intensity caused a decrease in the electrical efficiency of all fluids used. As the intensity of radiation increases, the temperature of the photovoltaic panel increases, which results in a decrease in electrical efficiency. However, the rate of efficiency drop is reduced by using nano-coolants. The highest electrical efficiency was recorded at 200 W/m², and the lowest efficiency was recorded at 1000 W/m² radiation. For a full day run, the percentages increase in electrical efficiency were 3.3%, 12.97%, 20.3, and 29.92% for adding 0.5%, 1.0%, 1.5% and 2.0% of nano-CuO water blends compared to water, respectively.

Figure 4. The effect of radiation intensity on PVT system electrical efficiency

Figure 5 shows the effect of the radiation intensity on the thermal efficiency produced from the examined PVT system. The increased radiation intensity causes a significant increase in the temperature of the PV panel. Circulating coolant fluid draws heat from the PVT panel, and the greater its thermal conductivity, the greater the amount of heat being drawn. Hence, the increase in thermal efficiency was evident as the radiation intensity increased. For full-day operation, the increase in thermal efficiencies were 12.65%, 26.9%, 37% and 61.08% for 0.5%, 1.0%, 1.5% and 2.0% of nano-CuO water blends compared to water, respectively.

Figure 6 illustrates the increments in total efficiencies for the tested coolants. PV panel generates electrical efficiency only while PVT panel produces electrical and thermal energies. The total efficiency of the PVT system is higher than that of the PV panel. Besides, the PVT panel cools by nanofluids has higher total efficiencies compared to the water-cooling system. For full-day operation, the increase in total efficiencies were 15.95%, 38.87%, 57.3%, and 91% for 0.5%, 1.0%, 1.5% and 2.0% of nano-CuO water blends compared to water, respectively.
4. Conclusions

In this study, the possibility of using nano-CuO added to water as a coolant in a PVT system was investigated. The study was carried out in the laboratory using a solar simulator, changing the intensity of radiation to simulate the movement of the sun during an entire day. The thermophysical properties of the prepared fluids were also studied with added mass fractions of nano CuO to water. Both the density and viscosity increased with increasing the proportion of nanoparticles added, but the increment rates were limited. The thermal conductivity of nanofluids increased dramatically compared to water, reaching 100.3% when adding 2% nano-CuO. Stability experiments showed that all the prepared nanofluids have good stability, and the fluid stability is increased by adding nanoparticles in a smaller amount. The use of nanofluids for cooling the PVT system resulted in improved electrical, thermal, and total efficiencies compared to water cooling alone. The maximum efficiencies obtained when adding 2% nano-CuO to the water were 29.92%, 61.08%, and 91% for electrical, thermal, and total efficiencies respectively.
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