COMPARATIVE ANALYSIS OF COPPER OXIDE (CuO)-BASED SPIRAL FLOW PHOTOVOLTAIC SHEET AND TUBE THERMAL SYSTEM

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Abstract

The current work investigates experimental characteristics of the Photovoltaic Thermal system integrated with CuO-Water spiral flow heat exchanger and compared with non-cooled PV module. The work describes detailed procedure of Nanoparticles (NPs) preparation, SEM characterizations and heat extraction characteristics of Nanofluid (NFs) in PVT application. The heat exchanger was pasted at the back of polycrystalline PV module to form PVT system to examine cooling ability, power generation, thermal-electrical yield and overall efficiency at a different volume concentration of CuO NPs at steady mass flow rate of 0.08 kg/sec. From the experiments, it was concluded that the CuO-Water NFs assisted to lessen surface temperature of PV module by extracting heat that enhanced electrical efficiency by an average of 3.53%. It was also seen that electrical and thermal performance was improved at higher volume concentration and overall efficiency of 30.77% and 36.59 % were obtained at 0.01% and 0.03% of volume concentration.

Key words: Solar Energy; Nanofluid; Cuo-Water; Volume Concentration; Electrical-Thermal Performance
1. Introduction

The modern energy sector prefers renewable sources over conventional fuels to fulfill energy demand that can also reduce widespread climate threats and global warming. From 1990 to 2017, highest average annual growth in the renewable sector of 37 % was seen for solar PV technology followed by 26% wind power according to IEA- International Energy Agency (2019). The solar PV technology is clean source of energy that converts solar radiation in to electricity without moving parts via photovoltaic effect. In the photovoltaic effect, the photons from sunlight fall on surface of semiconductor material and excited electrons generate potential difference gives rise to electrical power. The main factor limiting use of PV technology is reduction in magnitude of power generation at elevated PV surface temperature. However significant development in cooling technology made possible to enhance performance of PV module. The cooling fluid not only extracts heat from PV module but also extracted heat can be utilized for variety of energy applications. The combine PV system along with heat exchanger to offer cooling is known as Photo-voltaic Thermal (PVT) system [1].

The recent advancement in cooling technology was studied by Satpute, J. B. et al. (2018)[2], where they discussed water, air, PCM- Phase Change Material, refrigerant, nanofluid and combination of two or more fluids for PV cooling. Many researchers have used water and air as heat transfer medium to offer cooling and recuperate waste heat due to is ample availability, chemical stability, and low-cost characteristics. Konstantinos Ordoumpozanis, et al.(2017)[3], Swapnil Dubey et.al (2008)[4], Patrick Duperat et.al (2011)[5], Swapnil Dubey et.al (2012)[6], Pierrick Haurant et.al (2015)[7] performed parametric study with water as a working fluid to provide cooling and recover waste heat with various configuration of thermal absorber. Similarly H.G. Teo et al. (2012) [8], S.M. Bambrook at al. (2012) [9], J.K. Tonui et al. (2007) [10] studied air as a cooling medium for PV module. These conventional cooling fluids have the inherent constraint of lower thermal conductivity and heat transfer coefficient. In twenty-first century, the researchers were tuned towards up-gradation of conventional and well-accepted cooling mediums with nanofluid (NFs). The NFs is the composed blend of NPs suspended in a base fluid with a range of concentrations by volume or weight. Initially, researchers N. Taniguchi, (1974) [11] proposed “nanotechnology” as technology of manometer size material. The properly disperse NPs offered enhanced micro convective heat transfer, stability, surface to volume ratio.

Jee Joe Michael et al. (2015) [12] proposed PVT collector with copper sheet thermal absorber using CuO water NFs. The CuO water based PVT offered thermal efficiency up to 45.76 % whereas electrical efficiency was lowered compared to water-PVT. The work also suggests emphasizing on effective thermal absorber design to improve overall efficiency of PVT system. Mohammad Sardarabadi et al (2014) [13] proposed Silica-Water (SiO2-water) NFs at 1% and 3% weight concentration. Total exergy of 24.31 % was achieved with Silica-Water NFs at 3% weight concentration whereas it was 22.61 % and 19.36 % at 1% wt concentration and water-PVT respectively. Matin Ghadiri et al (2015) [14] did similar experimental work with ferro- NFs (Fe3O4-water) in PVT system. Since the ferrofluid changes its thermophysical properties during magnetic field, study was performed under constant and alternating magnetic field at 1% and 3% weight concentration.

The study concluded that alternating magnetic field of 50Hz with higher concentration enhance the PVT performance. Variety of NFs such as nanotube- H2O, Graphene-H2O, CuO-H2O, Al2O3- H2O, TiO2- H2O, and SiO2-H2O were proposed by Sujit Kumar Verma et al (2017)[15] for optimum concentration, mass flow rate, energy efficiency and entropy generation. They found multiwall nanotube-water as better NFs among all as at 0.75 % particle and flow rate of 0.025 kg/sec; energy efficiency of 23.47 % and entropy generation drop of 65.55 % was seen. R. Gangadevi et al (2018) [16] analyzed the thermo physical property of ZnO-water NFs and proposed it as a heat transport medium in the PV/T
application. In the work, experiments were conducted at 40L/H and concentration of 0.05, 0.1 and 0.2% respectively. The PVT efficiency was observed up to 93% at an upper volume concentration of 0.2%.

Hashim A. Hussein et al (2017) [17] presented performance improvement using Zn-H2O nanofluid in PV system under Iraqi weather conditions. The actively cooled pipe heat exchanger was designed and heat transport was investigated at five concentration ratios of 0.1, 0.2, 0.3, 0.4, and 0.5%. The nanometric size of NPs and heat transfer characteristics was investigated by Reza Davarnejad et al (2013) [18]. They proposed average 20 nm and 50 nm NPs size and performance results were compared with water. It was seen that nanofluid with 50 nm nanometric size demonstrated better average heat transport characteristics and Nusselt number due to higher surface area at increasing flow rate.

An indoor experimental work with multiwall carbon nanotube-water NFs was performed by R. Narsin et al (2018) [19] for PVT application and 87.65% of overall efficiency was recorded and numerically validated. The performance augmentation of PVT system with NFs cooling was endorsed by Ahmad Fudholi et al. (2019) [20]. The TiO2-Water NFs with 0.5 wt% and 1 wt% at varying solar concentration was studied under uniform mass flow rate. The PVT efficiency was raised to 89% with 1 wt% NFs whereas it was limited to 76% with water cooling. R Gangadevi et al (2017) [21] experimentally examined Al2O3-water NFs for PVT application in Chennai India to investigate overall performance. The spiral flow thermal absorber was proposed and Al2O3-water has circulated at mass flow rate of 40L/H with 1wt% and 2wt% concentration. The result endorsed a higher concentration of NFs for better performance as enhanced PVT efficiency of 58% was obtained during experimentation.

During the experimentation Garg et al (1994) [23] was discovered that for Ac = 2.0 m 2, P = 1.0, Mw = 100 kg, and m = 0.03 kg/s, approximately 340.9 Wh/day of directly converted electrical energy was available. A typical domestic solar water heater of around 2 m 2 produces enough electrical energy (after accounting for losses in storing, etc., as well as the effort required primarily by the pump) to power two 20 W tube lights for only 5 hours. Yildirim et al (2019) [24] concluded that most other Photovoltaic devices have lower seasonal self-sufficiency values than Mono-Si. Even among the numerous benefits PV areas determined based on annual load profile, CdTe has the best seasonal efficiency of 18 percent self-sufficiency in winter and 59 percent in summer. Throughout the FIT case, summer self-sufficiency with CdTe innovation appears to be 79 percent. In 2013, Panti et al (2016) [25] tested an efficiently oriented monocrystalline solar module of 60 Wp produced 62.9 kWh with electric power, a horizontal module 58.1 kWh, a vertical subsystem oriented towards its south 43.9 kWh, a vertical module focused towards to the east produced 25.7 kWh, as well as a vertical module oriented towards its west generated 22.9 kWh.

2. Nanofluid preparation and characterization

The analytic reagent grade Copper (II) chloride (CuCl2) and Potassium Hydroxide (KOH) from Merck India Ltd were taken in the experiment work and Copper oxide was synthesized using 500 ml of Copper chloride solution and alkali. An approach reported by Thi Ha Tran et al (2014) [22] was adopted for NPs preparation. The equimolar ratio of copper (II) chloride 0.1M and potassium hydroxide 0.5M pallets were separately dissolved in the deionized water. At normal pressure conditions, continuous stirring was maintained during dropwise accumulation of potassium hydroxide solution to copper (II) chloride hydrate to ensure uniform mixing. Then the mixture was heated to 70 °C for an hour and resulted black colored copper hydroxide solution was filtered twice using filter paper until it completely solidifies.

The black-colored solidified copper hydroxide was annealed at temperature of 200 °C in the electric muffle furnace for 3 hours to obtain crystalline structure. Finally, the sample was ground into fine powder form to obtain court-NPs and characterization were performed.
From the micrograph of copper oxide; one can observe the formation of grain boundaries with flake like morphology. Most of the flakes are irregular in shape with broad size distribution (~ 120–600 nm) due to particle aggregation with crystal growth at the time of synthesis. The congregate morphology plays an important role in crystal growth and also conserving energy and densification is driven as a counterpart of NFs.

**Figure 1** 1) Mixture of KOH And CuCl2, 2) Mixture + Water, 3) Precipitation, 4) Furnace heating, 5) CuO NPs

**Figure 2** Micrograph of copper oxide

3. **Experimental setup**

The setup was manufactured, assembled and installed at the terrace of institute to ensure maximum radiation will fall on PVT system. The two identical PV modules one with sheet and tube heat exchanger (PVT system) and another without heat exchanger (Non cooled PV module) were placed on same structure and exposed to ambient condition for experimental work. The copper material with high thermal conductivity (385W/mK) was used to manufacture round spiral heat exchanger and soldered to copper sheet. The copper sheet was pasted to the backside of PV panel and wooden blocks were used to make sure proper surface contact. The both end of the tube are connected with common tank of capacity 50 litre and centrifugal pump of 0.5 kW was used to circulate the CuO-Water NFs. The K-type thermocouples are incorporated for temperature measurement in experimental setup.

**Figure 3** Experimental Setup
4. Performance evaluation

The incident radiation on PVT system is main source of input to generate electrical and thermal energy. The various measuring instruments are used to record observations and discussed in methodology section. The measured quantities are used to analyze performance indicators as follows,

The PVT efficiency of CuO-Water NFs PVT ($\eta_{PVT}$) is function of electrical power, thermal power, incident radiation and PVT system area as per Garg H P (1995),

$$\eta_{PVT} = \frac{P_{\text{Thermal}} + P_{\text{electrical}}}{P_{\text{incident}}}$$

The thermal power of CuO-Water NFs PVT is expressed as,

$$P_{\text{thermal}} = m_f * c_p * (T_i - T_f)$$

Similarly, electrical output power is expresses as,

$$P_{\text{electrical}} = V_{oc} * I_{sc} * FF$$

Based on above evaluation, performance characteristics of thermal-electrical and overall efficiencies are evaluated as,

$$\eta_{\text{thermal}} = \frac{P_{\text{thermal}}}{I_R * A_{TC}}$$

$$\eta_{\text{electrical}} = \frac{P_{\text{electrical}}}{I_R * A_{PV}}$$

$$\eta_{PVT} = \eta_{\text{thermal}} + \eta_{\text{electrical}}$$

While preparing NFs, the weight of CuO for percent volume concentration was decided by.

% Volume concentration,

$$\phi = \left[ \frac{W_{CuO}}{\rho_{CuO}} \right] \left( \frac{W_{CuO} + W_f}{\rho_{CuO} + \rho_f} \right) * 100$$

$$\phi = \left[ \frac{W_{CuO}}{6300} \right] \left( \frac{W_{CuO} + 100}{6300 + 100} \right) * 100$$

Where density of CuO is 6300kg/m$^3$ and density of water is 1000kg/m$^3$. 
5. Result and Discussion

The outdoor experimentations were performed with longitude 18.7611° N, latitude 73.5572° E and tilt angle of 20 degree respectively in summer season. The readings were recorded in the month of May on clear days from 10:00 am to 15:30 pm after an interval of every half an hour and observation were used to evaluate performance characteristics.

5.1 Thermal Characteristics

The variation in surface temperature of PV and PVT system during testing period was plotted in fig. 5. As discussed in introduction part, NFs provide better convective heat transfer characteristics. It was seen that temperature of non-cooled PV module was continuously increasing up to 54.0 °C. when the CuO-Water NFs circulated through heat exchanger, surface temperature drop was observed. The temperature was reduced by 2.63 % and 6.12 % at 0.01 V% and 0.03 V% respectively. The ambient temperature variations were recorded and followed similar profile as that of PV, PVT surface temperature.

Fig 6 justified use of higher concentration NFs, as constant improved thermal efficiency was seen during test at 0.03 V%. The thermal performance is also function of incident radiation and heat exchanger design. With spiral flow heat exchanger, average thermal efficiency of 23.54% and 16.39 % was recorded for 0.03 V% and 0.01 V% respectively.
5.2 Electrical Characteristics

The maximum electrical power obtained is the product of voltage and current generated through PV and PVT system. As shown in fig 7. In case of non-cooled PV module, power generation continuously turns down due to rise in radiation and surface temperature value. In the figure, better performance was observed with CuO-Water NFs circulation. It is the result of PV surface temperature stabilization achieved with NFs. This drop of surface temperature amplified power generation capacity of PVT system. The electrical power of 37.35W, 32.78W and 28.09W generated through non cooled PV, 0.01 V% and 0.03 V% NFs PVT.

![Figure 7 Variation of electrical power in case of non-cooled PV, 0.01 V% and 0.03 V% CuO-Water NFs PVT](image)

The average electrical performance recorded for non-cooled PV module was 9.85% from fig. 8 whereas significant rise up to 12.88 % examined with 0.03 V%. The highest electrical efficiency of 15.2% was observed in noon period at 0.03 V% concentrations and least electrical efficiency of 3.84 % was recorded for non-cooled PV module in the afternoon period.

![Figure 8 Effect on electrical efficiency with non-cooled PV, 0.01 V% and 0.03 V% CuO NFs PVT](image)
5.3 Overall Characteristics

![Figure 9 Variation in overall performance in case of non-cooled PV, 0.01 V% and 0.03 V% CuO NFs PVT](image)

As seen in fig.9, the PVT system has more overall efficiency that PV module due concurrent generation of two forms of energy. The overall efficiency of 36.59 % and 30.77 % were recorded for CuO-Water NFs-PVT with 0.03 V% and 0.01 V%. On the other hand, it was limited to 9.85% for non-cooled PV module. It is important to note that noticeable improvement in electrical and thermal performance was acknowledged with NFs circulation.

6. Conclusion

A CuO-Water NFs PVT was designed and its outdoor performance was evaluated using 0.01% and 0.03% volume fraction at 0.08 kg/sec. In the experimental analysis, it was seen that CuO-Water NFs-PVT system caused cooling of the photovoltaic module and resulted in improved electrical performance compared to PV module. The higher heat transport was seen at higher concentration of NPs, which uplift electrical-thermal power gain. The thermal efficiency was increased from 16.39% at 0.01 V% to 23.54% at 0.03 V% whereas electrical efficiency was raised from 11.07 % to 12.88 % at constant flow rate of 0.08 kg/sec. The overall efficiency of the CuO-Water NFs-PVT system is much significant than the PV module alone. Based on outdoor observations from lower concentration, electrical-thermal performance was discussed and can be further improved with higher concentration and flow rate.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>$A_{PV}$</td>
<td>Area of PV Module; m$^2$</td>
</tr>
<tr>
<td>$A_{TC}$</td>
<td>Area of thermal collector; m$^2$</td>
</tr>
<tr>
<td>$C_p$</td>
<td>Specific heat; kJ/kg.k</td>
</tr>
<tr>
<td>FF</td>
<td>Fill factor</td>
</tr>
<tr>
<td>$I_{sc}$</td>
<td>Short Circuit current; Amp</td>
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<tr>
<td>$I_R$</td>
<td>Incident Radiation; W/m$^2$</td>
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<tr>
<td>$m_f$</td>
<td>Mass CuO-Water NFs flow rate; Kg/s</td>
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<tr>
<td>$P_{electrical}$</td>
<td>Electrical Power; Watt</td>
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<tr>
<td>$P_{thermal}$</td>
<td>Thermal Power; Watt</td>
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<tr>
<td>$P_{incident}$</td>
<td>Incident power; Watt</td>
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<tr>
<td>$T_i$</td>
<td>Inlet temperature of CuO-Water NFs; °C</td>
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<tr>
<td>$T_o$</td>
<td>Outlet temperature of CuO-Water NFs; °C</td>
</tr>
<tr>
<td>$V_{oc}$</td>
<td>Open Circuit voltage; Volt</td>
</tr>
<tr>
<td>$W_{CuO}$</td>
<td>Weight of CuO; Kg</td>
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<tr>
<td>$W_{bf}$</td>
<td>Weight of base fluid; Kg</td>
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\[ \eta_{\text{Thermal}} \quad \text{Thermal Efficiency} \\
\eta_{\text{Electrical}} \quad \text{Electrical Efficiency} \\
\eta_{\text{PVT}} \quad \text{Photovoltaic thermal efficiency} \\
\rho_{\text{CuO}} \quad \text{Density of CuO; kg/m}^3 \\
\rho_{\text{bf}} \quad \text{Density of base fluid} \\
\phi \quad \text{Percentage of Volume Concentration} \\

References


