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Comparative study of nanoparticles with saline water for effective PV/T and buried UPVC water distribution system

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ABSTRACT

The use of the photovoltaic (PV) system is increased in recent days for the effective conversion of light energy into a useful resource. The focus of this research is to enhance the production of thermal energy by adding nanofluids to the PV/T system. In this work, three different ZnO, CuO and carbon nanotubes (CNT) nanofluids are taken into consideration and they are dispersed in the saline water. In this research, the effect of various nanoparticles on the PV/T systems were studied experimentally. The nanofluids were dispersed and sonicated with saline water at different volume fractions of 0, 0.5, 1, 2.5 and 5 (vol.%). A series of tests conducted to measure the crucial parameters such as PV temperatures, electrical output, electrical efficiency, and overall efficiency. From the test results, it is found that the addition of nanofluids to the PV/T system enhances the thermal output and electrical efficiency. By making the comparative analysis it is understood, the nanofluids CNT and CuO perform better than ZnO. However, the efficiency of the system is enhanced significantly due to the saline content in the water. The heat-storing capacity of the water is reduced as the saline content increases and it is transported through the buried pipelines. On the other hand boiling point of the saline water is increased, thus it can be used to carry more heat during cooling PV panels.

Keywords: Photovoltaic; Nanofluids; Renewable energy; Saline water; Solar

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1. Introduction

In recent days, the intensive search of the alternative energy resources gained profound attention among the pioneers [1,2]. On the other end, the depletion of fossil fuels is evident. To compensate that there is vigorous research happening on biodiesel and hydrogen fuels, but solar energy expected to gain huge attention due to availability and zero-emission [3]. Few findings found solar panels are the better alternative for the efficient reduction in greenhouse gas emission. Although biofuels emit less greenhouse gases still there are some environmental effects that can be completely avoided by using hydrogen or solar energy. The solar energy is harvested using the thermal and electrical system [4]. Photovoltaic (PV) cells are widely used to convert solar power to useful electrical energy. However, the uses of the PV panels are not very efficient and cost-effective. For instance, using amorphous silicon, polycrystalline and monocrystalline silicon PV panel's record 9%, 15%, and 20% reduced efficiencies due to heating of panels.

Few studies reported for every 1°C, a 0.4% drop in the efficiency is recorded. Further, the addition of unwanted heat to the panel reduces the life span of the PV module

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owing to thermal degradation [5]. Recently, Manigandan and Kumar [6], made the relative analysis of the hybrid PV/T system. The nanofluids CuO and ZnO were dispersed in the water to enhance the performance of the panel irrespective of the working conditions. From the series of the test, they proved CuO performs better than ZnO in all volumetric concentrations. Although there is plenty of nanofluid literature available to enhance the PV/T system the study on the nanofluids in hot countries like India is very limited.

Further, the article which uses the saline water the medium is very few to the author's perspective [7]. With this in mind, the authors compared the effect of ZnO, CuO, and carbon nanotubes (CNT) on the PV/T system. The main focus of the study to find the influence of nanofluids on electrical and thermal efficiency. Further, the effectiveness of saline water transport to the power plant for extracting the unused nanoparticles and thermal energy.

2. Experimental setup

As shown revealed in Fig. 1, the outdoor experimental setup had been used with a movable stand with a tilting facility to accumulate more energy. The PV module is placed in the 30° tilt stand. The PV is constructed with the mechanical attachment at the backside of the 40 W mono-crystalline silicon modules for the saline water flow. The thermal conductivity paste is filled between the pipeline and the PV panel to ensure maximum conductivity [8]. Further, the variable feed pump is used to supply the working fluids throughout the PV/T collector. The stirrer is connected to the tank to avoid the setting of nanofluids at the bottom of the reservoir to achieve maximum performance [9].

The test was conducted in the period of June 2018 to September 2018 in Chennai (12.8730°N, 80.2219°E), India. A series of tests conducted in the module at a different fashion of 0, 0.5, 1, 2.5 and 5 (vol.%). The weights of the nanofluids are carried out using FA1004N electric balance. The detailed setup can be found in our previous article [6]. This setup had been validated with Abdallah et al. [10]. The nanoparticles are procured from Light Mach composites, India and the property is shown in Table 1. The pipeline length is 3m and the buried depth is 0.5 m. These nanofluids dispersed in deionized saline water using an ultrasonic vibrator (DAIHAN WUC DH.WUC.D22H, Light Mach laboratories , Chennai) at 24 kHz [11,12]. On the other hand, the thermal conductivity of the nanofluids measured using KD-2 thermocouple sensor [13].

Fig. 1. Experimental setup.

The electrical output [21] given by

$$P_{\text{input}} = \text{Current}(I) \times \text{Voltage}(V) \times \text{Panel area }(A) \tag{1}$$

The maximum power [14] output

$$P_{\text{maximum}} = V \times I \tag{2}$$

$$Q_s = \dot{m} \times C_{\text{nf}}\left(T_{\text{exit}} - T_{\text{inlet}}\right) \tag{3}$$

$\dot{m}$ is the mass flow rate of nanofluid (kg/s), T_e is the exit fluid temperature (°C) and T_i is the inlet fluid temperature (°C).

Electrical power is represented by:

$$\%P_E = \frac{P_{\text{cooled}} - P_{\text{reference power}}}{P_{\text{reference power}}} \times 100 \tag{4}$$

where P_E is the electrical power; cooled power (W); reference electrical power (W).

Electrical efficiency of the panel [15] is given by:

$$\eta_{\text{electrical}} = \frac{\text{Maximum power output}}{\text{power due to solar radiation}} \tag{5}$$

The thermal efficiency (η_{thermal}) [15] of the module due to an incident of sun rays can be measured by dividing them with the power out as follows:

$$\eta_{\text{th}} = \frac{Q_S}{\text{solar radiation}} \tag{6}$$

Total efficiency = Electrical efficiency + Thermal efficiency (7)

2.1. Uncertainty analysis

The uncertainties of the test setup are measured experimental setup was measured in this study and expressed in similar fashion base on our previous studies [16,17].

The partial derivative of the sensitivity of the result given by:

$$\frac{U_R}{R} = \sqrt{\left(\frac{X_n \partial R}{R \partial X_n}\right)^2 \frac{U_{X_n}^2}{X_n^2}} \tag{8}$$

Table 1
Properties of nanoparticle and base fluid [9]

Particle	Diameter (nm)	Density (kg/m^3)	Thermal conductivity (W/m°C)	Purity (%)
ZnO	35–55	3,912	30.25	99.99
CuO	35–50	6,308	33.12	99%
CNT	45–50	2,100	48	98.99%
Water	–	998.2	–	De-ionized

$$W_R = \sqrt{\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \ldots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2} \tag{9}$$

R is the resultant of all uncertainty during measurement given by $R = R(X_1, X_2, \ldots, X_n)$ and $\frac{\partial R}{\partial x_1}$ is the measured result sensitivity for a single variable. Table 2 shows the uncertainty of the instruments. The average of the error is below 5% which is in limits of the tolerance level.

3. Results and discussion

The series of tests conducted to measure the influence of PV module temperature, electrical output and electrical efficiency for different nanofluids. Based on the results the validation is carried out to find the optimized nanofluid which performances better in saline water in cooling the PV panel.

3.1. PV module temperature

Fig. 2 shows the influence of nanofluids on PV temperature. The test is carried out during the summer to ensure the capture of maximum possible solar radiation. During summer, the PV panel efficiency is affected due to the overheating of the panels. This is a major worry for the power generators. Thereby, the serious of steps taken to control the temperature of the panel during the power harvesting. Few notable works proved the introduction of nanofluids as the coolant can decrease the temperature by improving solar heating. The nanofluids ZnO, CuO, and CNT are added with saline water to reduce the temperature which enables the PV panel to achieve higher efficiency. All nanofluids reported a better reduction in the temperature of the PV panel due to the dissipation of heat. For instance, the average decrease in the temperature of the panel is 19% with nanofluids compared to the conventional panel. At 9.00 A.M., the temperature variation between the CNT and CuO was 15%.

During the mid-day, a significant amount of enhancement is seen for the CNT and CuO compared to ZnO and conventional PV panel. For the case, 25% for CNT, 17% for CuO and 14% for ZnO improvement are reported than conventional PV which is very profound.

3.2. Electrical output

Fig. 3 shows the electrical output from 9.30 A.M. to 4.00 P.M. From the Fig. 3, it is evident that the addition of nanofluids increases the electrical output significantly. For instance, at 12.30 P.M. the nanofluids ZnO, CuO and CNT showed a momentous improvement in the electrical output by reporting 11%, 12.5% and 18% increase than conventional PV. Meanwhile, CNT reported the appreciable enhancement in the electrical output than ZnO and CuO. This is mainly due to the dispersion of nanofluids on the saline water. A similar trend was reported by Nasrin et al. [18]. Initially, at 9.00 A.M. the electrical output is minimum as the radiation level is lower. At 12.30 P.M, the solar radiation increases to the maximum to report the higher electrical output without overheating the panel due to the influence of nanofluids.

Further, the nanofluids hold the electrical output steady when the solar radiation decreases after 2.00 P.M. From the above regard, CNT reports higher output, meanwhile the CuO and ZnO also reported decent output compared to convention PV [19]. For instance, at 1.00 P.M. the difference between CNT on ZnO and CuO is 3% and 2% respectively.

Table 2
Equipment and their uncertainty [6]

Equipment and model	Measurement section	Accuracy	Uncertainty
Digital multimeter	Voltage	±0.4% + 1 V	0.05 V
Digital multimeter	Ampere	±0.7% + 1 A	0.025 A
Pyranometer	Incident solar radiation	±10 W/m^2	5.8 W/m^2
K-Type thermocouple	Surface temperature	±0.25°C	0.14°C
PT100 thermocouple	Fluid temperature	±0.25°C	0.14°C
Hg thermometer	Atmosphere temperature	±0.25°C	0.25°C
Rotameter	Mass flow rate	±0.2 kg/s	1.15 kg/s

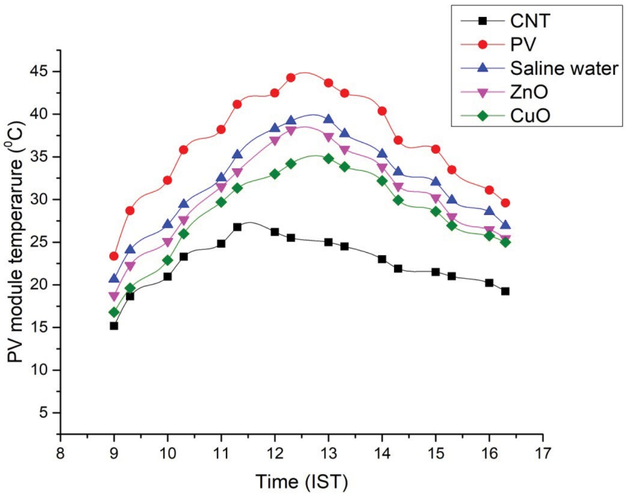

Fig. 2. PV module temperature for studied nanofluids.

3.3. Electrical efficiency

Although the electrical efficiency was improved by the addition of nanofluids, the improvement in the efficiency was slightly affected at 12.30 P.M. In other hands, at 9.00 A.M the electrical efficiency of the CNT is 18% and it is significantly reduced to 13% when the sun is at the peak position. Meanwhile, the other nanofluids also reported similar types of behavior, the respective drop in the thermal efficiency is 11% and 13% compared to CNT when the sun is at 12 o'clock position. Despite this drop, the average efficiency of all nanofluids is positive than conventional PV. The average electrical efficiency of the CNT, CuO and ZnO are 55%, 42% and 40%. From the above regard and Fig 4, CNT acting as the promising nanofluids than CuO and ZnO. To get a furthermore picture of the nanofluids, the total efficiency of the system is calibrated based on the derivation applied in our previous studies [6]. A series of tests conducted in a similar fashion to above to measure the total efficiency of the equipment, Fig. 5.

From the test, it is understood the CNT recorded a promising increase in efficiency than CuO, ZnO and conventional PV. Using the saline water alone in the tube doesn't record an appreciable result. However, the addition of nanofluids produces a good increase in the total efficiency of the PV/T. Simultaneously; the efficiency at the 12.30 P.M. is very huge and satisfying by employing the nanofluids.

For instance, at 9.00 A.M. the efficiency of the CuO, ZnO, and CNT are 33%, 34% and 42% which is increased to 65%, 68% and 75% when the sun is at the peak position. As the sun starts to descent the efficiency also dropped marginally and settled to approximately 48% for all nanofluids. When comparing with the conventional PV and saline water, the nanofluids reported a 35% increase in average efficiency. In regard to the exergy, CNT produces high exergy output than other nanofluids which is depicted in Fig. 6.

3.4. Transport of saline water

The saline water with nanoparticles issue out from the PV/T system after cooling the PV panel. To recycle the unused nanoparticles and to exact the thermal energy from the water, the water is transported through buried unplasticized polyvinyl chloride (UPVC) pipelines to the recycle power plant. Although the distance between the PV/T setup and the plant is short, however, there is a loss due to the nature of the buried pipelines. In addition, the external load acting on the pipelines also affects the effectiveness and exergy of the power plant.

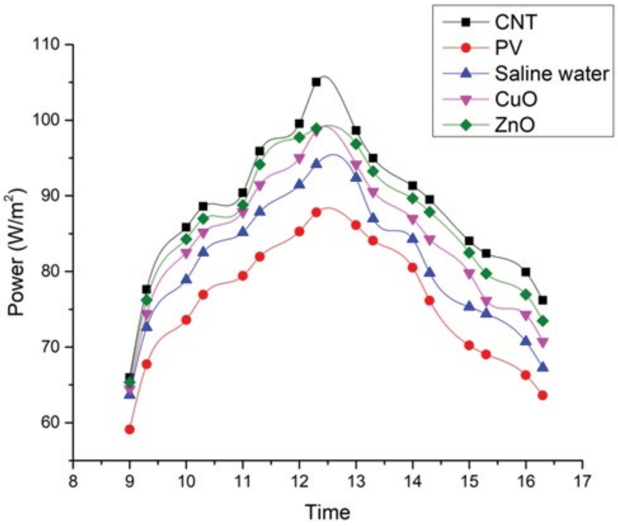

Fig. 3. Electrical output variation for the studied nanofluids.

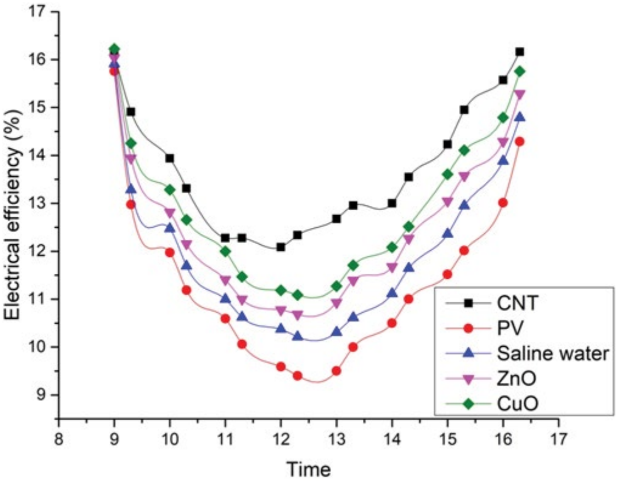

Fig. 4. Electrical efficiency for various nanofluids.

3.4.1. Ground load effect

The ground load determines the stress acting on the buried pipeline. If the stress is high than the applied load will be high. During small ground load, the von mises stress will be low. As the load increased, the stress is the polyvinyl chloride increases on both ends of pipelines which may lead to failure. As seen in the figure, there is no change in displacement and ovality up to 0.2 MPa. As the load goes beyond 0.2 MPa, the significant change in displacement and ovality

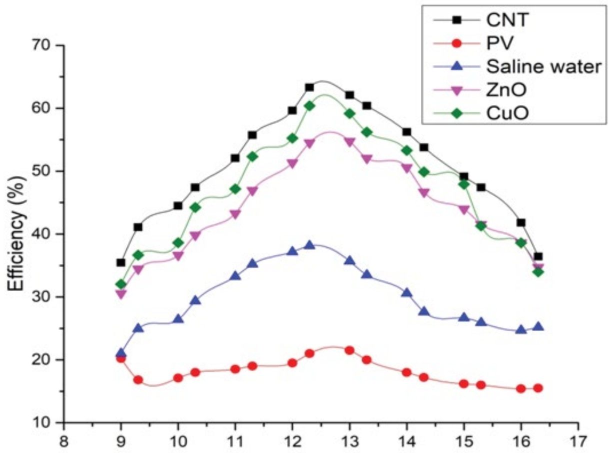

Fig. 5. Total efficiency for the studied nanofluids.

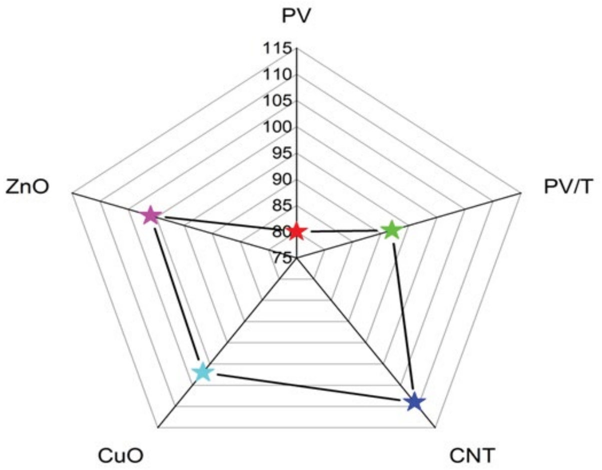

Fig. 6. Total exergy (W/m^2) for the studied nanofluids.

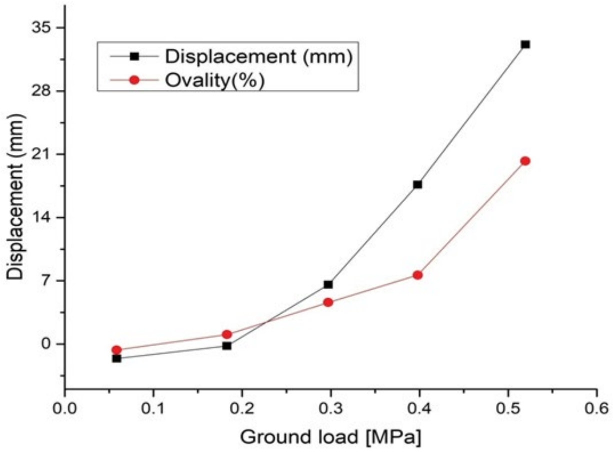

Fig. 7. Effect of ground load.

is noted. This acting was taken place due to the combined action of the pipeline and dune sand pressure on the pipelines. As the load increased further, the circular shape of the pipelines changes to the oval due to higher ground loading [20]. Ovality is the most serious issue seen in the analysis of pipelines. Generally, the ovality affects the flow rate of oil and gas. When the ground load is small, the ovality effect is negligible. As the load grew, the ovality will be bigger to dying to the inelastic phase of the pipelines. At 0.1 Mpa of load, the formation of ovality is very negligible but as the load increased for instance at 0.5 Mpa, the ovality increases 20% owing to the stress acting on the top layer of the buried pipe. Similarly, for every 0.1 MPa, the average change in the displacement is 80% to 84% as shown in Fig. 7.

4. Conclusion

The series of tests conducted in the outdoor conditions to monitor the performance of the nanofluids on the PV/T system. The nanofluids are dispersed and sonicated in the saline water for maximum stability without any deposition. The parameter such as PV temperature, electrical output, electrical efficiency, total efficiency and exergy is measured. The addition of nanofluids decreases the PV cell temperature incredibly in all working conditions. Specifically, CNT reported a drastic reduction in PV cell temperature than CuO and ZnO. The temperature decreases for the CNT, CuO and ZnO are 28%, 17%, and 15% respectively. The good improvement in electrical efficiency had been witnessed by the addition of nanofluids. The average electrical efficiency improvement is 60%, 50%, and 48% for the nanofluids CNT, CuO and ZnO. Regarding the overall efficiency, the CNT reported predominately better results than other nanofluids. For instance, the total efficiency of the CNT is 30% higher than conventional PV. In addition, the exergy of the system is analyzed and observed CNT reported better exergy than other nanofluids owing to the absorption rate with the saline water.

Symbols

PV/T	—	Photovoltaic thermal system
CNT	—	Carbon nanotubes
ZnO	—	Aluminium dioxide
CuO	—	Copper oxide
A	—	Panel area, m^2
I	—	Current, W/m^2
V	—	Voltage, V
P_E	—	Electrical power, W
P_{cooled}	—	Cooled power, W
$P_{\text{reference power}}$	—	Reference electrical power, W
η_{thermal}	—	Thermal efficiency, %
Q_s	—	Heat supply, J
wt.	—	Weight, kg
$\dot{m}$	—	Mass flow rate, kg/s
R	—	Given function of the independent variables
$\frac{\partial R}{\partial x_1}$	—	Measured result sensitivity for a single variable

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