Performance of Solar Photovoltaic panel using Forced convection of water-based CuO nanofluid: An Understanding

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Abstract. Most of the conventional Solar Photovoltaic module consists of a Silicon cell that converts sunlight into electric energy. The process of conversion into electricity is exothermic and all photons are not able to produce electricity due to insufficient energy. Depending upon efficiency to convert it into electricity only the small amount of radiations are used and rest all are involved in increasing the temperature of the module. Study shows that 80% of incident solar radiation are absorbed by a solar photovoltaic cell. This increases the temperature of the module, reduces its electrical efficiency. This increase in temperature affects the power output and lifespan of the PV module. So to maintain the temperature of the module various cooling methods such as air cooling, hydraulic cooling, heat pipe cooling, cooling with phase change materials and cooling with nanofluids have been reported in the literature. The use of suitable nanofluids is one of the effective methods to increase thermal capacitance and control the temperature rise of the PV module. To increase the performance of the system thermal properties of working fluid must be improved which is achieved by using suitable additives with the base fluid which are referred to as nanofluids. Using Copper oxide/water as a working fluid analysis was performed. It was concluded that performance can be improved significantly if we integrate the system with a good heat exchanger. In this paper, the effect of CuO based nanofluids as a cooling medium for a PV module has been reported.

Keywords: Solar photovoltaic, Thermal efficiency, Electrical efficiency, cut off voltage

1. Introduction
The concepts of photovoltaic and photoelectric effects have been going around for more than a century. Still, it is not able to utilize it in a large and fully profitable scale, the reason being its decreasing nature of electrical efficiency with the increase in surface temperature above the ambient value. It can convert solar irradiation into current energy [1-7]. The Solar Photovoltaic (SPV) converts visible, ultra-violet solar radiation to electricity. The infra-red solar radiation is converted into heat, which increases the cell temperature [8]. About 80% of solar radiation is absorbed by the PV cell, but not fully are converted into electricity. The efficiency to convert sunlight into electricity varies from 6% to 25% depending upon types of semiconductor materials used. There are also certain other factors like reflection, shadowing dust accumulation on PV panels which lowers efficiency. The temperature rise of the SPV panel, output power, fill factor and conversion efficiency decreases and thermal lattice vibrations increase [9, 10]. In the long term, there is an effect on the performance of the panel, if operated at high temperature. The electrical efficiency, open-circuit voltage, short circuit current and fill factor of the panel is decreased every year [11]. It is a known fact that the efficiency of the SPV exhibits a decreasing trend after the temperature of the cell goes above the ambient working temperature at a relative rate of about 0.45% to 0.5 % drop for every 1°C gain in the cell temperature.
The heat is lost to the surrounding by convective and radiative heat transfer but it is not very much appreciable [12-15].

2. Effect of temperature on photovoltaic cell
An increase in temperature decreases the band-gap which increases intrinsic carrier concentration which tends to upsurge the dark saturation current of PN junction due to which efficiency decreases. The study shows that this upsurge in dark saturation current causes a decrease in 0.5\% of efficiency for a rise in each degree centigrade temperature above operating temperature. The experimental investigation was performed by scientist Huang et al. [16] to observe the effect of operating temperature. The output of SPV decreases by 0.2–0.5%/ °C increase in panel temperature. Its effect is on voltage output also. This property of PV cells arises due to its linear dependence with module temperature and having a negative slope of $\beta_{\text{ref}}$. This slope is termed as the temperature coefficient of the cell. Various aspects of efficiency are discussed later in this paper.

### Table 1: Temperature coefficients of different SPV cell [16]

| $T_{\text{ref}}$ (°C) | $D T_{\text{ref}}$ (%) | $\beta_{\text{ref}}$ (°C) | PV Technology |
|----------------------|----------------------|-----------------------|-----------------|
| 25                   | 16–24                | 0.0041                | Mono-cSi         |
| 25                   | 14–28                | 0.004                 | Poly-cSi         |
| 25                   | 4-10                 | 0.011                 | a-Si             |
| 25                   | 8-12                 | 0.0048                | CIS              |
| 25                   | 10-11                | 0.00035               | CdTe             |

3. Nanofluids
It is the mixture of particles metallic particles of nano-metered size and liquids, which is referred nanofluids [17-20]. The heat transfer characteristics depend on the thermal conductivity of fluids which flows as coolant in the channel as well as flow parameters. The use of various types of nanoparticles such as carbide ceramics, metals, semiconductors, single, multi-walled carbon nanotube (MWCNT), alloyed nanoparticles has been reported to increase the heat transfer. The liquid in which particles are mixed is called base fluids. The common base fluids are such as H$_2$O, Ethylene glycol, Therminol VP1, lubricants, etc. The thermophysical properties of the fluids modified as compared to the base fluids. It has a higher specific area between particles and fluids. The stability of colloidal suspension very important. For heat transfer applications, thermodynamics and transport properties are important. This is varied by controlling the concentration or volumetric faction of nano-particles in the base fluids. The heat transfer characteristics depend on its nanoparticle material, base fluid, particle shape, size, and the thermal conductivity of both base fluids as well as the particles. Researchers tried several techniques for maintaining the temperature of the panel at a lower temperature. The cooling technique is active and passive cooling. The air, water, nanofluids, etc are used in active flow whereas phase change materials like paraffin wax, organic materials, eutectics are used as passive technique. Several researchers suggested different methods to improve the electric output of the SPV panel. Heating and cooling applications in industries, heat-carrying fluids play a vital role. The most common types of base fluids include water and ethylene glycol. The application heat transfer is very important for efficient system design [21-25].

4. Synthesis
For the preparation of nanofluids, a one-step technique and two-step technique are mostly used. In the two-step method after the production of nanoparticles is done separately then the dispersion of nanoparticles in the base fluid is done. This method is suitable for mass production. There is a possibility of cluster formation which resists proper dispersion. The one-step technique employs the production, as well as dispersion, is done in a single step. This technique provides better particle dispersion as compared to the two-step process, but this technique is not suitable for mass production which makes it costly.
4.1 Possible mechanisms for thermal conduction in Nanofluids
I. Brownian motion (diffusion process): This theory suggests that due to the incessant motion of the nanoparticles when two nanoparticles collide with each other, overall heat transfer increases due to the overall increase in the thermal conductivity of the nanofluids.
II. Liquid Layering: The liquid and solid atoms generate an oscillatory motion the direction normal to the interface.
III. Nano Particles Aggregation: The agglomeration of nanoparticles in the fluid leads to a formation of clusters of lower thermal resistance which is favorable.

4.2 Limitations of using nanofluids:
I. Production of homogeneous suspension of nanoparticles and maintaining it for a long duration is not easy due to the presence of strong Vander Waals forces between them. It may coalesce easily.
II. Higher viscosity than the base fluid increases the pumping power of the system to maintain the flow. Due to the increase in the value of volumetric fraction also increases the pumping power.
III. They tend to have a lower specific heat.

5. Experimental Observation
The use of copper oxide nanofluids were reported by Michael and Iniyan [26]. They conducted experimental very low discharge rate (0.01 kg/s) with 0.05% volume concentration. By use of nanofluids the heat transfer coefficient was increased about 10% as compared to the water only. The thermal efficiency is improved up to 45%. This is due to higher thermal diffusivity of nanofluids. The experiment indicated that CuO/water is best as a cooling medium to increase both thermal and electrical efficiency. The combined system can be used for electrical as well as thermal energy requirement. There are further scope of improvement by using another nanofluids having more thermal diffusivity. The comparative study of nanofluids have been reported by Al-Waeli et al [27].

6. Mathematical Modelling
Total energy absorbed [28] by the module is given by:

\[ E_{\text{abs}} = p \alpha_c \tau_g G \]  

(1)

Where \( p = \) packing factor, \( \alpha_c = \) Absorptivity of cell and \( \tau_g = \) Fraction transmitted through the glass

The electrical energy produced by solar radiation is given by:

\[ E_e = \eta_e p \tau_g G \]  

(2)

The heat energy released by the cell is the difference of total heat energy absorbed and the electrical energy converted. This energy raises the temperature of the panel which is given by

\[ E_{\text{gain}} = E_{\text{abs}} - E_e \]

\[ E_{\text{gain}} = p \alpha_c \tau_g G - \eta_e p \tau_g G \]

\[ E_{\text{gain}} = p \alpha_c \tau_g G \left( 1 - \frac{\eta_e}{\alpha_c} \right) \]

When considering PV systems, two types of efficiencies are taken into consideration:
(a) Thermal efficiency: It is the ratio of the total amount of heat energy extraction from the system and total incident radiative power from the sun.

\[ \eta_{\text{thermal}} = \frac{\text{Heat gain by fluids}}{\text{Heat received by panel}} \]
\[ \eta_{\text{thermal}} = \frac{\text{mass flow rate of fluids} \times \text{Specific heat} \times \text{Temperature gain}}{\text{Incident solar radiation} \times \text{Area of panel}} \]

\[ \eta_{\text{thermal}} = \frac{mc_p(To - Ti)}{GA} \]

(b) Electrical efficiency: The electrical efficiency of a panel is the ratio of maximum electrical power produced to total incident radiative solar power. Mathematically,

\[ \eta_{\text{electrical}} = \frac{E_{\text{el}}}{E_{\text{in}}} = \frac{V_{oc} \times I_{sc} \times FF}{G_{\text{eff}}} \]

Where, \( I_{sc} \) = Short circuit current, \( V_{oc} \) = Open circuit voltage. FF = Fill factor

\( G_{\text{eff}} \) = effective absorbed solar irradiation by the module

The fill factor defined as the maximum power conversion efficiency of the module which is a function of the temperature of the module.

7. CuO/Water as a nanofluid:
The properties of CuO, Water, and CuO/water nanofluids are calculated from the equations mentioned above at 300K and are listed in Table 2 as below:

| Property          | CuO      | Water | CuO/Water nanofluid (3% vol. fraction) |
|-------------------|----------|-------|---------------------------------------|
| \( C_p (J/kgK) \) | 533.157  | 4179  | 3516.43                               |
| \( \rho (g/cm^3) \) | 6.31     | 1     | 1.18054                               |
| \( k(W/mK) \)     | 33       | 0.617 | 0.678                                 |
| \( \mu (kg/ms) \) | -        | 0.00091 | 0.000987                            |

It can be seen from the calculations that the thermal conductivity of nanofluids is increased from the base fluid water from 0.617 W/m K to 0.678 W/m K, which amounts to an increase of 9.88% in the overall thermal conductivity of the nanofluids.

8. Conclusion
About 80% of solar irradiation is either reflected or absorbed by the SPV cell and 20% is converted into electric power. The efficiency decreases due to an increase in the temperature of the module. This increase in temperature affects the power output and lifespan of the PV module. To operate the PV module at low temperature, various active and passive techniques have been used in literature like air cooling, hydraulic cooling, heat pipe cooling, use of PCM and application of nanofluids can be used. Using nanofluids flow, the solar photovoltaic modules can be operated at a lower temperature. The CuO/Water-based nanofluids as a cooling medium can be used. This will help in understanding the behavior of the solar panel with application of nanofluids as coolant in SPV module.

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