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Improvement of Solar Cell Efficiency and Electrical Energy of a Photovoltaic-Thermal System by Using Nanofluid

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ABSTRACT

This communication presents the finite element method (FEM) analysis of the conjugate heat transfer across the PV/T panel. The PV/T system has several layers i.e., PV cell layer, thermal paste layer, reservoir wall and reservoir flow channel filled with nanofluid. The heat transfer equations for all layers have been constructed according to the conjugate heat transfer equation. The continuity, momentum and energy equations are solved numerically by using the FEM technique. The effects of various dimensionless parameters are discussed by plotting velocity, temperature, electrical output and thermal efficiencies. The result indicates that the average cell temperature keeps decreased by increasing nanoparticle concentration. The narrower flow channel has greater power output at the relatively low concentration while the wider flow channel has greater power output at the relatively high concentration. Thermal performance increases by 11% for every 10% increasing in nanoparticle volume fraction.

Keywords: Conjugate heat transfer; nanofluid; FEM; photovoltaic; thermal system

INTRODUCTION

Energy is the most important needs for humans since ancient times, all activities carried out by humans always need energy, be it activities carried out by humans themselves or with the help of tools that make it easier for humans to carry out all their activities. The creation of a sense of comfort in the presence of energy will make the human connection with energy even greater. Accompanied by the times and advances in technology, the demand for energy will increase and continue to increase in the fields of transportation, economy, social, electricity and so on. The rapid increase in the global population together with their daily advances requirements needs a larger and smarter implementation of energy. Renewable energy sources provide 14% of the total world energy supply (Demirbas 2006). The sources come from the sun, biomass, hydropower, geothermal, and wind energies. These sources are the main, local, clean and green property energy reserve. Shafiee & Topal (2009) described the availability and limited stocks of fossil fuels and other non-renewable energy resources.

Solar energy is the cheaper and cleaner energy source for all human beings. The energy from solar radiation intercepted by the earth is about 1.8×10^{11} MW, which is several times greater than the total amount of global energy consumption, Parida et al. (2011). Photovoltaic (PV) technology is one of the smartest ways to collect solar energy. Yang et al. (2012) demonstrated that the new PV technology enhances energy saving, for example, multi-junction cells, modifying the optical frequency and concentrating PV However, these techniques are too expensive. They configured the injection of cooling fluid at varied flow rates through the tubes to decrease the PV/T panel temperature and it slightly increases the electrical and thermal efficiency. Teo et al. (2012) considered the energetic cooling method where the produced heat from the PV modules were cooled by forced convection. This method improved electrical efficiency by 4-5%. Hariharan et al. (2016) proposed a new technique to scan PV module faults and partial darkening in the PV panel. Rahman et al. (2017) studied the impact of environmental conditions on the electrical efficiency of PV panels operating in Malaysia. They came to the conclusion that sun energy does not convert to 100% electrical energy, around 80% is transformed to thermal energy. Santiago et al. (2018), Poulek et al. (2018) and Sanchez-Palencia et al. (2019 indicated that the thermal energy increases the PV's temperature, which will reduce its performance. PV and thermal (PV/T) system could be integrated into the PV module as one piece of the new device. The combination of the thermal system in the PV module functions as a heat absorber on the surface of the PV module, so that the temperature in the PV arrays can be reduced and their performance can increase. In addition, the heat energy released from the PV array can be further utilized in many applications, Diwania et al. (2020).

Basic PV panel heats up under sunlight. The overall impact to enhance the temperature where it reduces the electrical efficiency and reliability. Researchers have investigated and studied a number of ways to cool PV cells. Zhu et al. (2014) propose a common technique to radiatively lower the PV temperature via sky access while keeping active solar absorption. Li et al. (2017) described the photonic approach for solar cell cooling. Amanlou et al. (2018) considered the air cooling to keep from the local high temperature on the PV panel, uniformity of cold airflow as working fluid in the PV/T collector. Sato & Yamada (2019) reviewed the cooling methods of the PV module and performance assessment of the radiative cooling technique. They concluded that changing the surface emissivity spectrum has little effect on radiative cooling. Nanofluids are a mix of a cooling fluid and a solid nanoparticle, in the range of 1 nm to 100 nm. These advanced heat transfer fluids have the potential to improve heat transfer performance of free convection insides rectangular enclosure, Khanafer et al. (2003), Ogut (2009), Rashmi et al. (2011), Sheikhzadeh et al. (2013). Taylor¨ et al. (2012) described an optimization theory for configuring nanofluid-based filters for PV/T utilization. Mallah et al. (2019) considered the plasmonic nanofluids for high photothermal conversion efficiency in direct absorption solar collectors. Singh & Khullar (2019) demonstrated an optimal absorption solar thermal system utilizing nanofluids based on selective oil. They demonstrated that nanofluids possess exceptional qualities as a possible working fluid in volumetric absorption solar thermal systems. Farhana et al. (2019) reviewed the enhancement in the performance of solar collectors with nanofluids and concluded that long-term stability is the basic and essential requirement of nanofluids. Trong T. et al. (2020) considered the carbon-water nanofluids for direct thermal solar collectors. Goel et al. (2020) conducted a systematic review of nanofluids in designing hybrid PV/T and steam generation collectors. They indicated that the PV and thermal systems need to be split up. Huaxu et al. (2020) investigated experimentally the economical aspect of zinc oxide nanofluid based spectral splitting CPV/T configurations. Okonkwo et al. (2020) reviewed several cooling devices utilizing nanofluids. They discovered that if the heat capacity of base fluids is greater than that of nanoparticles, an increase in nanoparticle volume concentration reduces the specific heat capacity of nanofluids. Sahin et al. (2020) gave the latest update on the performance improvement of solar energy systems using nanofluids.

Based on the previous literature analysis, investigation on free convection in a parallel plate channel filled with nanofluids still has not yet been further studied. The thin channel space in which nanofluid will circulate through and brings heat away from the PV panel. Using alumina nanoparticles prevents flow clogging caused by bridges, which happens as the number of microparticles goes up. Alumina nanoparticles are a type of metal oxide nanoparticle with a wide range of applications due to their exceptional physicochemical and morphological properties such as resistance to wear, chemicals, and mechanical stresses, together with their favorable optical properties and a porous vast surface area. Another reason for the extensive use of alumina is their low cost of fabrication and ease of handling. Channel with PVT configuration for water as working was firstly studied by Jones & Underwood (2001) and later extended by Nahar et al. (2019). Combinations of utilizations of nanofluids at various flow rates and various concentration of nanoparticle were analyzed to obtain the maximum thermal efficiencies. Other influences to PV cell temperature, outlet temperature, rate of thermal energy and electrical energy output are also being included. Hence, this work has been elaborated to generate more results with illustrations and graphs on nanofluid temperature behavior inside the reservoir channel.

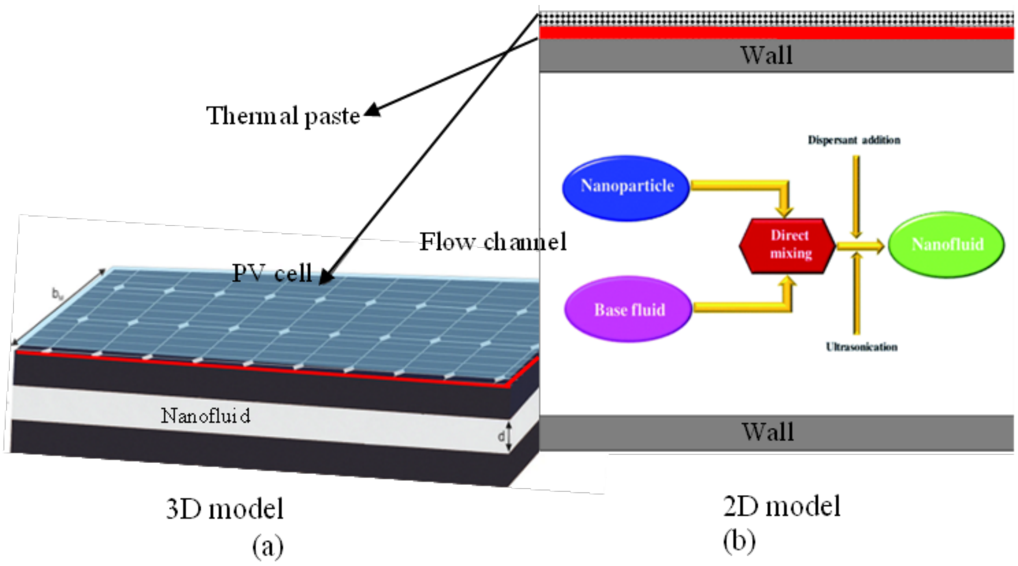


FIGURE 1. Schematic 3D model (a) and 2D model (b) of PV/T solar panel and the reservoir channel filled with nanofluid

MATHEMATICAL FORMULATION

Schematic photovoltaic-thermal (PV/T) solar panel in this research were modeled in Figure 1. PV/T system has several layers, PV cell layer, thermal paste layer, reservoir wall and reservoir flow channel filled with nanofluid. The PV cell layer is an electrical part that directly converts light energy into electricity through the photovoltaic effect. A photovoltaic device is one whose electrical properties, such as current, voltage, or resistance, change when it is exposed to light.

In this study as shown in Figure 1(a), the 3D model, the PV panel design has a side, 30.5 cm and thickness 0.27 mm. Monocrystalline silison PV (c-Si) was used, because these cells absorb more heat than polycrystalline silicon PV (p-Si), where the surface temperature of monocrystalline (c-Si) will be higher than that of the polycrystalline (p-Si) in the same environmental condition. A typical c-Si cell has a heat coefficient of 0.54 with 13% of photovoltaic conversion efficiency. The thermal paste layer is the conductor material with a dimension of 30.5 cm × 30.5 cm × 0.3 cm. The wall of the reservoir is made of aluminum and is 30.5 cm × 30.5 cm × 1 mm. The 3D model was simplified so that the technical problem could be treated as a 2D model, Figure 1(b). The 2D geometry is a vertical slice or middle layer of the 3D geometry. To simplify 3D to 2D, the reservoir must be assumed to be homogeneous. In addition, the finite dimension of the parallel plate geometry providing the two-dimensional flow is the optimal option. The reservoir flow channel is used as a layer for fluid flow, where nanofluids contain solid particles and water with a volume fraction from 1 % to 20 %. The nanofluid is considered laminar with velocity is assumed to be 0.01 m/s and the thickness of the reservoir wall is assumed to be 0.015 m.

The heat transfer equations for the PV cell layer, thermal paste layer, reservoir wall, reservoir flow channel have been constructed according to the conjugate heat transfer equation. The PV surface has a constant and uniform temperature variation. The sky was considered as a black body for long-wavelength radiation at environmental conditions. Dust free is assumed to enable full transmission of energy from the sun. Table 1 shows the incoming physical properties from the sun and environmental conditions.

TABLE 1. The incoming energy properties from the sun and ambient conditions

Distance (m)	Quantity name	Value
G (kg/m^2)	Solar Irradiance	1000
h_c (W/(m^{2}K))	Heat transfer coefficient	6.5
T_{amb} (K)	Ambient temperature	298.15
ε (kg/m^2)	Radiation emissivity	0.3

The PV panel as sketched in Figure 1 is subject to energy from the sunlight, converts some of the irradiances into electricity via the photovoltaic effect and the remaining irradiance becomes heat. The irradiance exposes the whole plate. The purpose of using the thermal paste below the PV array is to diffuse the big amount of heat to increase electrical efficiency. The heat convection on the top and bottom interface of a PV panel is stated as:

$$q_{conv} = -h_c\, A\left(T_{pv} - T_{amb}\right) \quad (1)$$

Where h_c is heat loss due to convection and A is surface area. The overall conjugate convection is a mix of the heat transfer at the top and bottom interface of the PV/T panel and the energy from the nanofluid flow in the reservoir. The electromagnetic radiation emitted by the surface and atmosphere in the form of infrared heat loss can be stated as:

$$q_{lw} = \varepsilon.\sigma\left(T_{pv}^4 - T_{amb}^4\right) \quad (2)$$

where ε radiation emissivity and σ is the electrical conductivity. Determining the extinction, absorption and scattering coefficients were the important issues in modeling thermal radiation in participating media. The extinction coefficient of the medium:

$$K_e = \frac{1.5\Phi Q_e}{d} + (1 - \Phi)\frac{4\pi K_{bf}}{\lambda} \quad (3)$$

where Q_e the extinction coefficient of the nanoparticles, λ is radiation wavelength, d is nanoparticles diameter. K_{bf} is the extinction of water could be evaluated as:

$$K_{bf} = K_a + K_s \quad (4)$$

where K_a and K_s are the absorption and scattering coefficient, respectively, see Table 2 for the reference value

TABLE 2. Thermo-physical properties of water with aluminum oxide nanoparticles

Properties	Water	Aluminum oxide
Cp (J/kg K)	324.70	324.78
ρ (kg/m^3)	163.46	163.16
k (W/ m K)	103.70	103.42
μ (kg/ms)	73.46	74.38
K_s (1/m) and K_a(1/m)	1 and 8	-

For all layers, the heat is transferring from nanofluid to solid or solid to nanofluid or even conducting through solid layers via the mode of conjugate convection. The nanofluid at the inlet channel has a uniform temperature. The hybrid concept is applied to enable a solar cell to convert solar radiation into electrical energy at peak conditions. Most of the received solar energy is converted into heat, this heat will cause an increase in the solar cell temperature. This temperature increase can be exploited employing the cooling system on the PV/T module with nanofluid, so the electrical energy produced is maximized. To obtain efficiency, various calculation equations are used. When the sun's heat shines on PV and there is solar energy that cannot be utilized properly in the form of heat on the surface of the panel, then the heat conduction through the PV cell, thermal paste and reservoir walls can be stated as:

$$\nabla.(k\nabla T) = 0 \quad (6)$$

Inside the channel heat transfer occurs by convection and conduction. The flow brings by inlet velocity and from the heat transfer is considered to be steady, incompressible, Newtonian and laminar. Solid nanoparticles were considered to have uniform shape and size and in thermal equilibrium condition with the host fluid. The particles are nano-size aluminum oxide, see Table 2 for the thermo-physical values. The density difference with the temperature in the gravitational force term is assumed to be linear based on Boussinesq's model. The model is accurate when density variations are small enough no impact on the convective flow, except that they give rise to gravitational forces, based on this consideration the continuity, momentum, energy stated as:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \quad (7)$$

$$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{1}{\rho_{nf}}\frac{\partial P}{\partial X} + \frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right) \quad (8)$$

$$U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{1}{\rho_{nf}}\frac{\partial P}{\partial Y} + \frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) + \beta_{nf} g(T - T_{amb}) \quad (8)$$

$$U\frac{\partial T}{\partial X} + V\frac{\partial T}{\partial Y} = \alpha_{nf}\left(\frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial Y^2}\right) + \frac{1}{(\rho C_p)_{nf}}\nabla.Q_r \quad (9)$$

Here (*U*, *V*) are velocities vector, *T* is temperature and *P* is pressure. Subscript *nf* refers to the bulk properties of the nanofluid, g is the acceleration due to gravity, μ, *ρ*, β and α are dynamic viscosity, the density, thermal expansion and thermal diffusivity of the nanofluid at room temperature, respectively. The density of the nanofluid is written as a weighted relation of the water and dispersed particles,

$$\rho_{nf} = (1 - \Phi)\rho_{bf} + \Phi\rho_{sp} \quad (10)$$

where ϕ is the nanoparticles volume fraction. Subscript *bf* refers to the base fluid or water. The dynamic viscosity of the nanofluid is written as:

$$\mu_{nf} = \frac{\mu_{bf}}{(1-\Phi)^{2.5}} \quad (11)$$

Thermal diffusivity of the nanofluid is:

$$\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}} \quad (12)$$

where, the heat capacitance is:

$$(\rho C_p)_{nf} = (1 - \Phi)(\rho C_p)_{bf} + \Phi(\rho C_p)_{sp} \quad (13)$$

The thermal expansion coefficient of the nanofluids can be determined by:

$$\beta_{nf} = (1 - \Phi)\beta_{bf} + \Phi\beta_{sp} \quad (14)$$

The thermal conductivity of the nanofluid is derived from the Maxwell equation:

$$k_{nf} = k_{bf}\left[\frac{k_p + 2k_{bf} - 2(k_p - k_f)\Phi}{k_p + 2k_{bf} + (k_p - k_f)\Phi}\right] \quad (15)$$

Equations (5) to (15) were solved numerically using the finite element method (FEM) via Comsol. This method will be described in the next section. After solving Eqs. (5) to (15) then the PV cell electrical efficiency is evaluated by the following equation:

$$\eta_{pv} = \eta_{ref}\left[1 - \beta_{ref}(T_{pv} - T_{ref})\right] \quad (16)$$

Electrical energy output is the total amount of dynamical electric potential energy SI unit joule/second or Watt. The formula to calculate this output yielded by the PV/T system is:

$$E_{pv} = \eta_{pv} \times A_m \times G \quad (17)$$

The electrical output was formulated as a function of PV cell efficiency, the PV cell surface area and solar irradiance. The received electrical energy by PV module exposed to solar irradiance is defined as:

$$E_{in} = G.A_m \quad (18)$$

The extracted thermal energy using nanofluid as PV/T cooling is evaluated as:

$$E_{nf} = m_{nf} C_p (T_{out} - T_{in}) \quad (19)$$

Thermal energy percentage that successfully converted into electrical energy could be calculated using:

$$\eta_{th} = \frac{E_{nf}}{E_{in}} \times 100\% \quad (20)$$

The overall or global efficiency of PV/T system is a summation of the electrical energy output and the thermal energy over the received electrical energy as follow:

$$\eta_{glob} = \frac{E_{nf} + E_{pv}}{E_{in}} \times 100\% \quad (21)$$

MATHEMATICAL FORMULATION

The continuity, momentum and energy equations are solved numerically by using the Finite Element Method (FEM) via Comsol. The principle of FEM is dividing the domain into sub-domains. We consider the following application modes in Comsol. The incompressible flow, laminar flow (spf) for equations (6)–(8), the heat transfer in fluids (ht) for equation (9). The irradiance was determined by using constant heat flux.

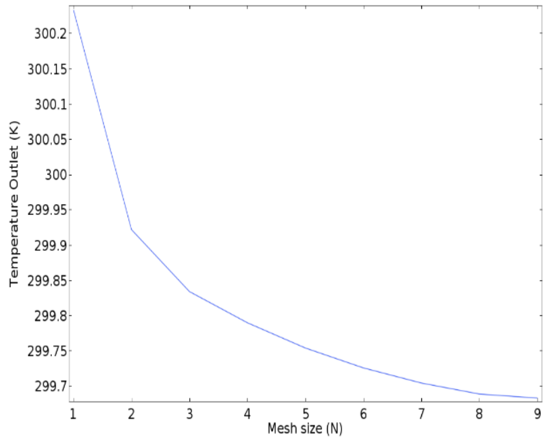
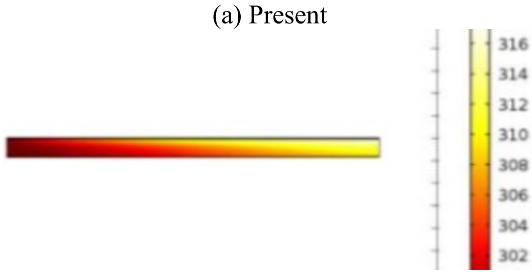


FIGURE 2. Varying mesh sizes effect to the outlet temperature at u_{in}=0.001 m/s, d=0.015 m and ϕ=0.05

Various grid sizes are compared to select a grid with good accuracy and low computational time. Grid development of the domain is performed into a regular mesh. The grid was stretched with the default stretching ratio near the walls to adequately capture the thermal layer, and the grid becoming coarse towards the middle of the channel. To achieved optimal grid size, several tests were performed i.e.: extremely coarse (N1), extra coarse (N2), coarser (N3), coarse (N4), normal (N5), fine (N6), finer (N7), extra fine (N8) and extremely (N9) as shown in Figure 2. For this, the outlet temperature values outlet at 5% solid concentration was considered. The N8 uniform mesh size is chosen for all computations in this paper for related problems to this subsection. This mesh consists of 19200 domain elements. As a validation, current works (b) of temperature is validated with that obtained by Fontenault and Gutierrez-Miravete (2012).

(a) Present



(b) Fontenault and Gutierrez-Miravete (2012)

FIGURE 3. Validation of present (a) isotherms with published (b) work for u_{in}=0.001 m/s, *d*=0.015 m and pure water case.

RESULT AND DISCUSSION

The numerical simulations consider the inlet temperature was of uniform temperature which is room temperature. This temperature was selected to adapt a case where the working fluid may reach room temperature before entering the channel inlet to transport heat away from the solar panel. Parametric studies are applied to analyse the PV cell temperature, PV cell efficiency, electrical energy output, outlet temperature, thermal efficiency, rate of thermal energy and total energy efficiency by varying the nanoparticles volume fraction from 0% to 20%.

Figure 4 shows a plot the outlet velocity profiles for three cases inlet flow velocity and different nanoparticles concentration at d=0.015m. It is apparent that the no-slip condition applied on the walls and the parabolic velocity profile was developed. The velocity increases in the middle with increasing the concentration for cases (a) and (b). However, the velocity in both cases decreases with increasing the concentration in the left and right portion of the channel for both cases. The outlet velocity keeps almost constant everywhere at case (c).

Figure 5 shows a surface plot of the temperature pattern for pure water case (a) and nanofluid case (b) at a channel width of 0.015 m and the inlet flow velocity is 0.001 m/s. The no-slip condition applied on the walls channel and the parabolic velocity plot was formed in a long distance from the inlet. This causes in a higher temperature gradient at the PV/T system for pure water and nanofluid. The impact of fluid acceleration due to adding nanoparticles on the temperature gradient and the system cooler was obviously presented in this figure. Cell temperature variation by varying the nanoparticle concentration from 0% - 20% will be shown in the next figure.

Figure 6 shows the average surface temperature of the PV cell plotted against nanoparticles concentration for different channel width at the inlet flow velocity is 0.001 m/s. It can be deduced that the higher concentration, the lower the average PV/T surface temperature will be. As the fluid temperature increases in the channel, the thermal difference between the cell and the fluid decreases, resulting in a decreased thermal gradient across the channel-thermal paste interface. The cell temperature at 1% solid concentration is about 314.5 K and 313.7 K for d=0.015 m and d=0.01 m, respectively. Then, the temperature keeps decreased and later by adding more nanoparticles the average cell temperature reduction of larger channel size is more pronounced than the d=0.01m case. This due to the thermal energy produced by the PV/T system would be absorbed so that the outlet temperature of the reservoir was kept cold. A slight reduction in temperature bring in significant differences in thermal efficiency; therefore, accurate temperature measurement is necessary for precise results

Figure 7, the PV cell efficiency is plotted against nanoparticles concentration at the inlet flow velocity is 0.001 m/s for two channel width, d=0.015 m and d=0.01 m. It can be deduced that the higher concentration, the higher the PV cell efficiency will be for both conditions. It is observable that an increase in the volume fraction of nanoparticles results in a reduced PV cell temperature. Initially, d=0.01 m exhibits better enhancement than the d=0.015m. The efficiency keeps increased and later by adding more nanoparticles the efficiency of larger channel size is greater than the d=0.01 m. This sensitivity of the cell efficiency to the volume fraction of nanoparticles is equivalent to the increased viscosity at a high-volume fraction of nanoparticles, where high concentration causes the nanofluid to become more viscous which leads the velocity to attenuate following the channel size that finally yields different reducing level of the PV temperature.

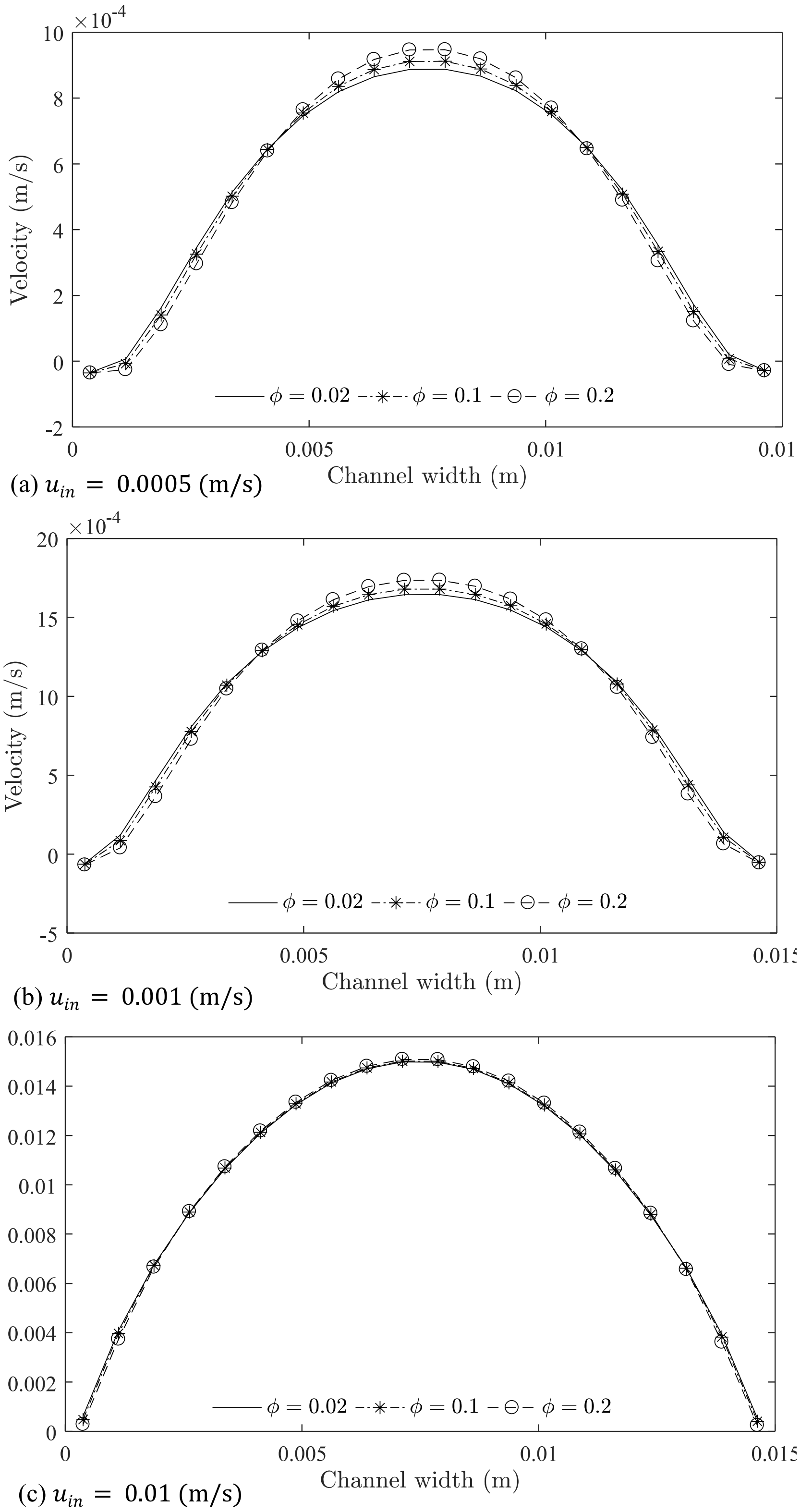
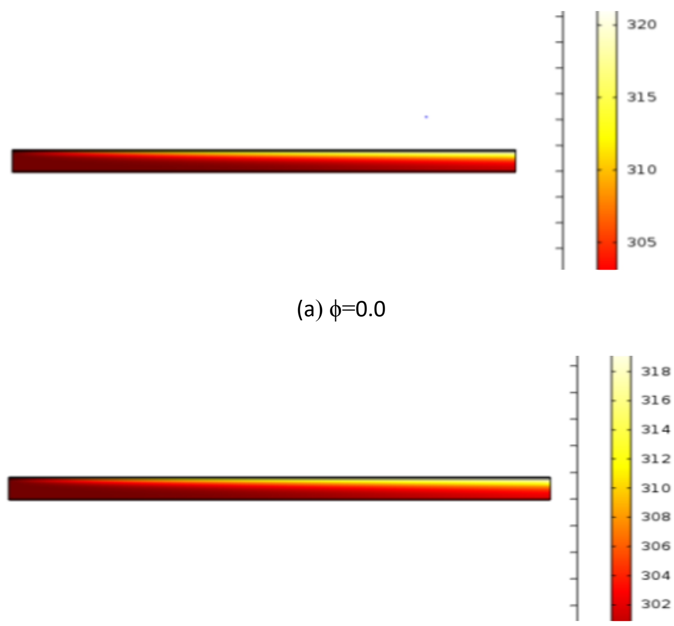


FIGURE 4. Outlet velocity profiles for three cases inlet flow velocity, case u_{in}=0.0005 m/s (a), case u_{in}=0.001 m/s (b), case u_{in}=0.01 m/s (c) and different nanoparticles concentration at *d*=0.015 m

Figure 8 shows the electrical energy output by increasing nanoparticle concentration at the inlet flow velocity is 0.001 m/s for two channel width, d=0.015 m and d=0.01 m. For low nanoparticle concentration, the power is much lower than for high nanoparticle concentration. This is due to the denser concentration to enhance the thermal performance of the system. This due to thermal performance strongly depends on nanofluid flow circulation. It notes that all of the solar irradiances were converted to electrical and as mention previously it depends on the thermal efficiency of the silicon cell. At the highest concentration was observed that the energy output achieves the greatest value. The electrical energy keeps increased and later by adding more nanoparticles the power enhancement of larger channel size is more pronounced than the *d*=0.01 m case. Actually, the wider flow channels result in lower flow velocity but the very high aluminum oxide concentration has a significant impact when the channel is wide enough.

Figure 9 shows the nanofluid thermal efficiency by increasing nanoparticle concentration at the inlet flow velocity is 0.001 m/s for two channel width, d=0.015 m and *d*=0.01 m. For low nanoparticle concentration, the thermal efficiency is much lower than for high nanoparticle concentration. This is due to the larger volume fraction of the solid, which naturally circulates faster than the smaller volume of the suspended aluminum oxide. The reason is that thermal efficiency depends on the heat transfer. PV cell layer, thermal paste layer, wall layer, and nanofluid layer comprise the PV/T system. It is noticed for each layer if heat is moving from fluid to solid, solid to fluid, solid to solid, or even conducting through solid sections, and most crucially, whether the mechanism of heat transfer is pure convective or primarily by convection with heat conduction assisting. This also considering all of the photon energy does not transform into electrical energy would be developed into thermal energy. The PV/T system partly absorbs some of the solar irradiance exposed on the PV cell because of the different wavelengths or frequencies. In addition, the surface of the PV would not always clear all the time, which would impact the overall absorptivity. Thus, a proportional decreasing in thermal efficiency could be predicted. The thermal efficiency of *d*=0.015 m case is much higher than of *d*=0.01 m case. Thermal performance increases by 11 % for every 10 % increase in nanoparticle volume fraction. This is owing to the fact that heat transfer enhances as channel depth and concentration increases.

Global energy efficiency is modified by adjusting the nanoparticle volume fraction as presented in Figure 10. At low concentration, the total energy efficiency of PV/T system is about 69.5% for *d*=0.015 m case and 66.5% for *d*=0.01 m case. When the nanoparticle volume fraction is set denser, the total efficiency keeps higher. The enhancement trend in total energy efficiency for both channel size is minor. Thermal energy produced by the PV/T system would be absorbed so that the outlet temperature of the reservoir was kept cold. A wider channel has greater overall energy efficiency for any volume of nanoparticles fraction. Total energy harvesting increases by 6% for every 10% increase in nanoparticle volume fraction.



(a) ϕ=0.0

(b) ϕ=0.05

FIGURE 5. Surface plot of the temperature pattern for pure water case (a) and nanofluid case (b) at u_{in}=0.001 m/s and *d*=0.015 m

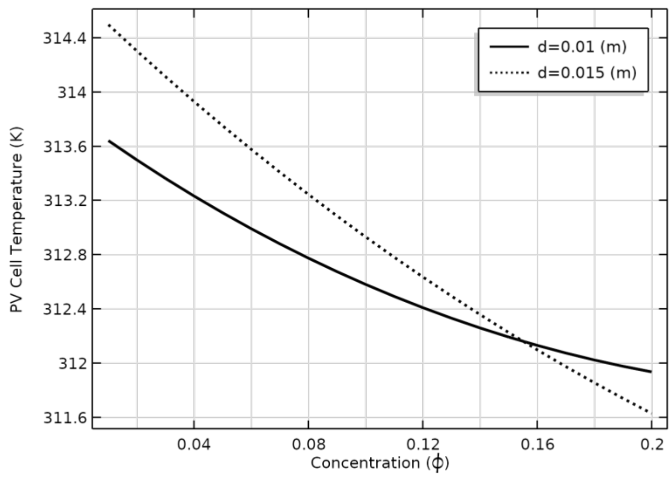


FIGURE 6. The average surface temperature of the PV cell is plotted against nanoparticles concentration at u_{in}=0.001 m/s

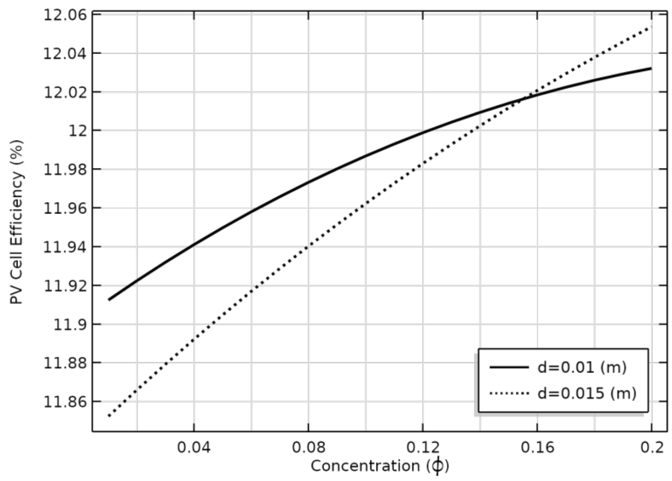


FIGURE 7. PV cell efficiency against nanoparticles concentration at u_{in}=0.001 m/s

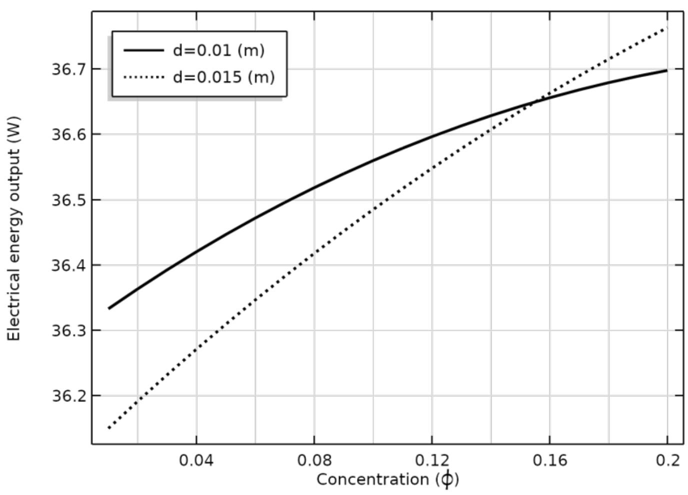


FIGURE 8. Electrical energy output from PV/T against nanoparticles concentration at u_{in}=0.001 m/s

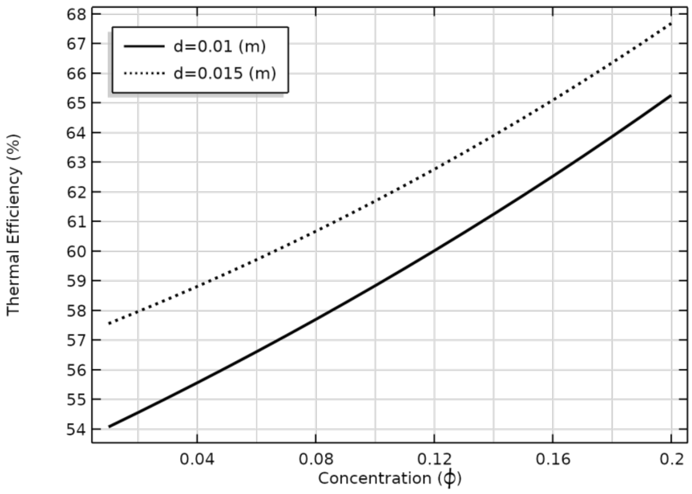


FIGURE 9. The efficiency of the PV thermal system against nanoparticles concentration at u_{in}=0.001 m/s

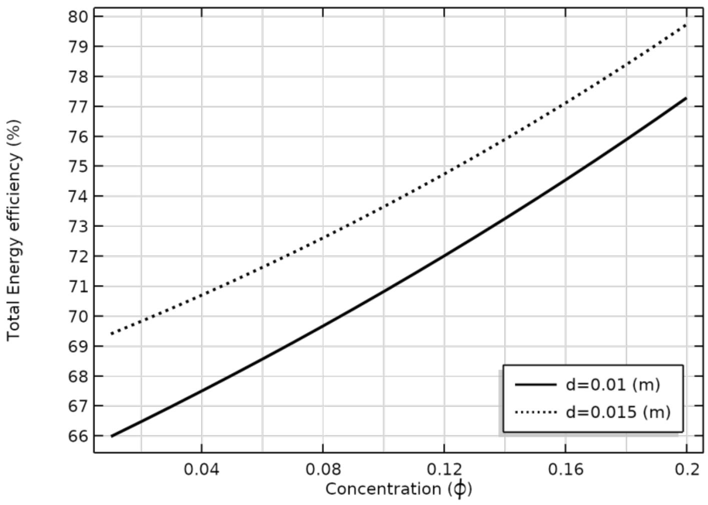


FIGURE 10. The global energy efficiency of the PV thermal system versus nanoparticles concentration at u_{in}=0.001 m/s

CONCLUSION

In this simulation, a conceptual PV/T configuration was studied using FEM. The PV/T panel is made from monocrystalline with a thermal paste underneath and an aluminum channel through which coolant nanofluid is pumped. Various simulations were conducted to model the conjugate convection across the PV/T panel and calculate the electrical energy output and thermal efficiencies. Nanoparticle volume fraction was adjusted and analysed to find which combinations yield not only the highest total PV/T efficiency but also the best thermal and power output. The main conclusions of the present analysis are as follows:

1. The outlet velocity keeps almost constant everywhere by varying the nanoparticle volume fraction at the highest inlet flow velocity. Increasing nanoparticle volume fraction capable to increase the maximum velocity at low and moderate values of the inlet velocity.
2. The PV cell efficiency and electrical energy output keep increasing by adding more nanoparticles for the considered parameters in this work. The narrower flow channel has better efficiency and greater power output at the relatively low concentration while the wider flow channel has better efficiency and greater power output at the relatively high concentration.
3. Thermal performance increases by 11% for every 10% increasing in nanoparticle volume fraction with 6% enhancement of the total energy efficiency.

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DECLARATION OF COMPETING INTEREST

None

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