Available online at www.rajournals.in

RA JOURNAL OF APPLIED RESEARCH
ISSN: 2394-6709
DOI:10.31142/rajar/v5i1.07
Volume: 05 Issue: 01 January -2019

International Open Access
ICV- 74.25
Impact Factor :5.985
Page no.- 2248-2268

Modelling and Simulation of Performance of Nanofluids in PV-Thermal Solar Panel Collectors

S. Sami[1,2]

[1] Research Center for Renewable Energy Catholic University of Cuenca, Cuenca, Ecuador
[2] TransPacific Energy, Inc, NV, 89183, US

ARTICLE INFO

Published Online:
31 January 2019

Corresponding Author:
S. Sami

ABSTRACT

A numerical mathematical model has been developed to predict the performance of Nano fluids in Photovoltaic-Thermalsolar collectors. The model is based upon energy conservation equations for nanofluids flow and heat transfer mechanisms for different nanofluids. The thermal dynamic behavior of the PV-Thermal solar collectors and heat transfer fluid has been studied numerically and analyzed under different nanofluid particles concentrations and different conditions. Comparisons were made against literature data for validation purposes of the predictive model. The model fairly predicted nanofluids conditions and compared well existing data on the subject.

KEYWORDS: PV-Thermal solar panels, nanofluids, dynamic thermal behavior, numerical model, simulation, validation.

1. INTRODUCTION

Today, most photovoltaic solar panels provide an energy efficiency rating between 11 and 15 percent, which is the percentage of solar energy that is being converted into useable electricity. It may seem like a low percentage, however, advancements in solar energy technologies are continually being made, and modern PV panels can do more than cover the energy requirements of most commercial and residential needs. Today, researchers are continually trying to improve the efficiency of photovoltaic technology. Currently the most advanced and efficient solar cells are being developed, however, they are not yet available to the general public.

In order to improve the solar photovoltaic's(PV) efficiency, references [1-19] developed and implemented a novel concept of combined photovoltaic-thermal solar panel hybrid system where the PV cells of the solar PV panels are cooled by water flows. The excess thermal energy is generated and dissipated due to the intrinsic conversion efficiency limitation of the cell. Consequently, the dissipated and excess thermal energy increases the cell temperature and in turn reduces the conversion efficiency of the cell. The excess thermal energy absorbed by the cold-water flow though the heat exchanger thermal panel underneath the PV's cells can be used for various domestic or industrial applications. Therefore, the net result is an enhancement of the combined photovoltaic-thermal efficiency of the hybrid system and consequently the PV solar panel.

Research in nanofluid which is a fluid with suspensions of nano-sized particles has been reported in the literature [20-34]. Choi defined the term nanofluid and the suspensions of nano-sized particles (1-100 nm) in a conventional fluid base called nanofluid [25]. Computation of thermophysical properties of nanofluids such as thermal conductivity, viscosity, density and specific heat as well as thermal diffusivity are essential to understand their heat transfer behavior [20-22].

Nanofluids exhibit improved thermophysical and heat transfer properties such as thermal conductivity, viscosity and convective heat transfer coefficient. The property improvement of nanofluids depends significantly on the volumetric fraction or concentration of nanofluids particles, shape and size of nanofluid materials[20-37].

Thermal solar water heating systems are compromised mainly of thermal solar panels, a thermal storage tank and a pump. In this particular study, the heat transfer fluid (HTF) delivers the heat absorbed at the heat exchanger thermal panel underneath the PV's cells to the storage thermal tank. Therefore, the solar energy is converted into electricity and the excess heat is delivered to the thermal storage tank for further thermal use.

References [20-27] have investigated the use of nanofluids in solar collectors and its impact on the enhancement of efficiency of flat solar collectors. However, Taylor et al. [31] investigated theoretically and experimentally the nanofluids in a laboratory large-scale dish receive rutilising power tower solar collectors Enhancement of efficiency was observed compared to the base fluid [13-27]. On the other hand, Khullar et al. [33] studied the enhancement of solar irradiance absorption capacity of nanofluid-based concentrating parabolic solar collectors, theoretically and compared the results with experimental data from a conventional concentrating parabolic solar collector. The results of his study demonstrated 5-10 % a higher efficiency compared to conventional models.

More recently Sami [20, 32] presented a study, on the characteristics of heat transfer fluid with nano particles AI2O3, CuO, Fe304 and SiO2 circulating in thermal solar panel and thermal tank During the course of the study, Reference [20] modeled, presented, analyzed the characteristics of the nanofluids fluid flow and compared the model’s prediction to data published in the literature.

A mathematical model is presented hereby to describe the heat and mass balances of the heat transfer fluid flow using nanofluids to absorb the excess heat released from energy conversion process in PV solar panels. The model has been established after the energy and mass conservation equations coupled with the heat transfer equationsof the heat transfer fluid.In the following sections, the simulation results of a PV-TH solar panel using the different nanofluids will be presented and analyzed. In addition, the simulated results are compared with available data on nanofluids. This mathematical model, in particular,can be used topredict the PV-TH solar panel behaviour under the effect of different operating conditions such as solar radiation, working fluid flow rates, initial working fluid temperatures and nanofluid concentrations.

MATHEMATICAL MODEL

A schematic of the PV-thermal solar system under study is depicted in Figure.1. The system consists of a PV solar panel, thermal solar panel collector, thermal tank, and piping, pump and as control valves. The thermal tank was equipped with the single tube heat exchanger to supply the heat for domestic or industrial use.The hybrid system in question is composed of the PV solar panel and Thermal solar tube collector and thermal tank as shown in Figure.1. In the hybrid system, thin parallel tubes are welded on the backside of photovoltaic solar panel for the circulation of the cooling fluid. The various flow tubes are in contact with the PV solar panel. The flow in each tube is divided into different elements to permit the finite difference formulation and analysis of the flow. The model is based on the following assumptions; the Heat Transfer Fluid, HTF, with nanofluids is homogeneous and isotropic, HTF is incompressible and can be considered as a Newtonian fluid, inlet velocity and inlet temperature of the HTF are constant, thermophysical properties of the HTF and nanofluids are constant. In the following, the conservation mass and energy equations and heat transfer equations are written and presented for each element of the HTF.

Solar PV MODEL

The solar photovoltaic panel is constructed of various modules and each module is consisted of arrays and cells. The dynamic current output can be obtained as follows [10-15], [16], and [17, 20];

$$I_P = I_L - I_o\left[\exp\left(\frac{q(V + I_P R_S)}{AkT_C} - \frac{V + I_P R_S}{R_{sh}}\right)\right] \tag{1}$$

I_p: Output current of the PV module
I_L : Light generated current per module
I_o : Reverse saturation current per module
V : Terminal voltage per module
R_s : Diode series resistance per module
R_{sh} : Diode shunt resistance per module
q: Electric charge
k : The Boltzman constant
A : Diode ideality factor for the module

Where;

$$I_o = BT^3 c\left[\exp\left(-\frac{E_{go}}{KT_C}\right)\right] \tag{2}$$

And;

$$I_L = P_1 G\left[1 - P_2\left(G - G_r\right) + P_3\left(T_C - T_r\right)\right] \tag{3}$$

The PV cell temperature, Tc, in equation (1) is influenced by various factors such as solar radiation, ambient conditions, and wind speed. It is well known that the cell temperature impacts the PV output current, and performance, and its time-variation can be determined from references [11-17]. The AC power of the inverter output P(t) is calculated using the inverter efficiency η_{inv} , output voltage between phases, neutral V_{fn}, and for single-phase current, I_o and the power factor, $cos\varphi$ as follows;

$$P(t) = \sqrt{3}\eta_{inv}V_{fn}I_o cos\varphi \tag{4}$$

PV THERMAL MODEL

It is assumed in this model that all PV cells behave the same; therefore, this model can be applied to the whole PV solar panel. This model is an extension of the model presented by Sami and Campoverde [11,12].

The heat absorbed by the PV solar cell can be calculated by the following [11, 12, 17, 37];

$$Q_{in} = \alpha_{abs} G S_p \tag{5}$$

Where;
α_{abs}: Overall absorption coefficient
G: Total Solar radiation incident on the PV module
S_p: Total area of the PV module

Meanwhile, the PV cell Temperature is computed from the following heat balance [11,17, 20];

$$mC_{p\_module}\frac{dT_C}{dt} = Q_{in} - Q_{conv} - Q_{elect} \quad (6)$$

Where;
T_C: PV Cell Temperature
mC_{p_module}: Thermal capacity of the PV module
t: time
Q_{in}: Energy received due to solar irradiation, equation (4)
Q_{conv}: Energy loss due to Convection
Q_{elect}: Electrical power generated

Interested readers in the detailed calculations of the terms; Qin,Qconv, and Qelect in equation (6) are advised to consult references [11,12] and [17] and [20].

Thermal energy incident in a PV cell

The thermal energy transferred from the PV cell to the Heat Transfer Fluid (HTF) is determined from the heat balance across the PV cell and HTF in terms of the heat transfer mechanisms; conduction, convection and radiation as follows [11];

$$Q_{conduction}=Q_{convection}-Q_{radiation} \quad (7)$$

The heat transfer by conduction is;

$$Q_{conduction} = \frac{K_{Pv} \times \Delta T(T_c - T_m)}{L_{cell}} \quad (8)$$

T_m: Module Back-surface temperature
K_{Pv}: Thermal conductivity of PV cell
L_{cell}: Length of a PV cell

The heat transfer by convection is determined from;

$$Q_{convection} = h_{water} \times \Delta T(T_m - T_f) \quad (9)$$

$Q_{convection}$: Energy due to convection
h_{water}: Heat transfer coefficient
T_f:Fluid temperature

And the heat transfer by radiation is;

$$Q_{radiation} = \varepsilon \times \sigma(T_m{}^4 - T_f{}^4) \quad (10)$$

$Q_{convection}$: Energy due to radiation
ε: Emissivity PV cell
σ : Stefan-Boltzmann constant

The finite difference formulation is used to determine the heat transfer fluidflow rate and its temperatures at each element where each heat transfer fluid tube is divided into number of finite control volumes, and where thermophysical and thermodynamic properties are assumed constant at each element;

$$T_f = T_{f\_in} + \frac{\partial Q}{m_{water} C_p} \times t \quad (11)$$

$\dot{m}_w$: Water mass flow (HTF)
C_p: Specific heat of water.
t: time
δQ: the heat transfer per element
T_{f_in}: Fluid temperature at inlet

The thermal energy transferred from the back of the PV cell to the heat transfer fluid (HTF) is obtained by;

$$Q_{Thermal} = \dot{m} \times C_{p\_water} \times \Delta T(T_{fHx+1} - T_{f\_In}) \quad (12)$$

Where;
$Q_{Thermal}$: Energy from thermal process
T_{fHx+1}: Fluid temperature at thermal element (f+1)
$T_{f\text{-}in}$: Fluid temperature at thermal element (1)

The total energy transferred to heat transfer fluid is calculated from the integration of equations (6) through (12) written for each element, dx, along the length of each tube.

The back-temperature T_m of the PV cell and PV panel can be calculated from the heat balance across the PV cell as follows [11, 17, 37];

$$Q_{in} = mC_{p\_module}\Delta T = mC_{p\_module}(T_C - T_m) \quad (13)$$

Where; $T_m$is the module back-surface temperature.

It is assumed that the $T_m$is equal to the surface temperature of the heat exchanger tubes welded to the solar PV cell/panel in close contact to the back surface of each of the PV cells.

The heat transferred from the back of the PV cell to the heat transfer fluid (HTF)flowing in the heat exchanger tubes as shown in Figure,1 is computed by the following forced heat transfer convection relationship [16,17, 37];

$$Q_{in} = \pi D L h_{water}\Delta T = \pi D L h_{water}(T_m - T_f) \quad (14)$$

Where;
D:Pipe diameter
L:Pipe length
h_{water}:Forced convection heat transfer coefficient
T_f:Fluid temperature

Where the heat transfer coefficient,$h_{water,}$ is approximated as [11, 17, 20];

$$hw = \frac{K_w}{D_H} b_2 Re^n \quad (15)$$

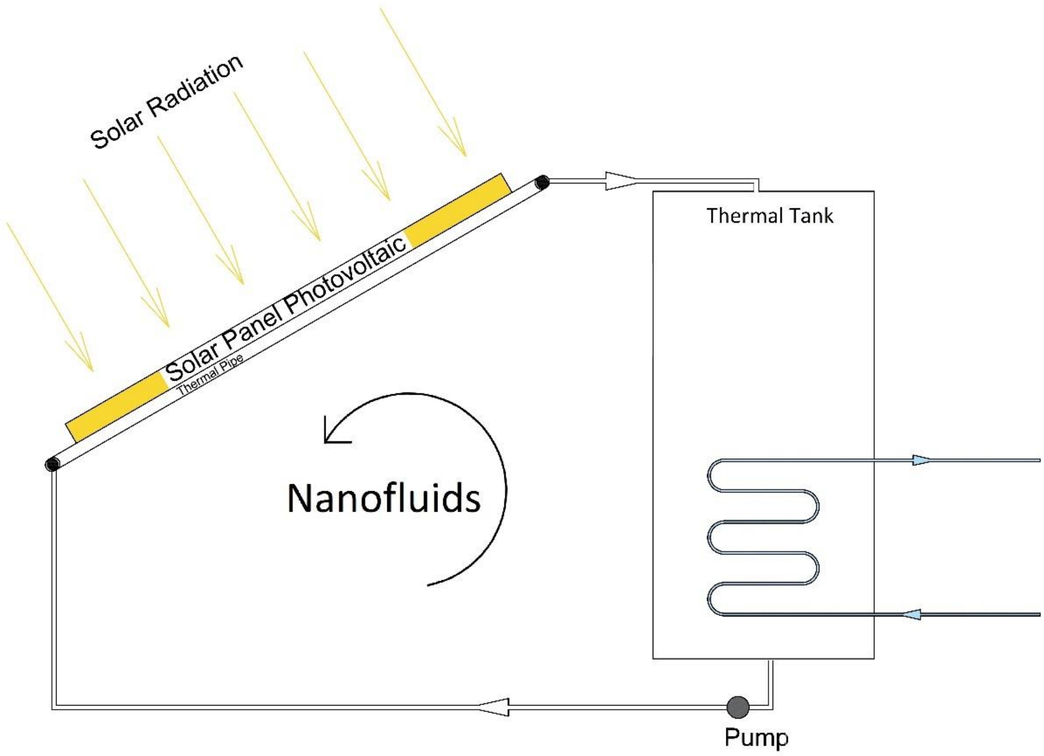

Figure 1: PV/Thermal hybrid system with Nanofluids

Where Re; is the Reynolds Number and K_w represents thermal conductivity of water, b_2 and n are numerical constants

Furthermore, to calculate the heat transfer fluid (HTF) flow rate, circulating in the heat exchanger tubes, the following equation is used coupled with equations (14) and (15);

$$Q_{in} = \dot{m}_w C_{p\_water} (T_{f+1} - T_f) \quad (16)$$

$\dot{m}_w$ represents the water mass flow rate and;
T_{f+1}: Water temperature at the element f+1
T_f: Water temperature at the element f
C_p: Specific heat of HTF.

The thermophysical, thermodynamic and heat transfer properties such as viscosity, thermal conductivity, specific heat, anddensity of nanofluids have been determined by various investigators through experiments as reported in Sharama et al. [31].Where equations have been developed and reported for specific heat, thermal conductivity, viscosity and density employing the law of mixtures and the data has shown that those equations were valid when compared with the experimental data.

: : Heat Transfer Fluid HTF flow rate : Specific heat of heat transfer fluid

: : Reynolds number Volume of water thermal tank

Once the nano particles are injected into the fluid base (HTF), the thermophysical, thermodynamic and heat transfer properties of the HTF with nano particles can be calculated as a function of the volumetric concentration of the nano particles flowing in the fluid flow as follows;

$$\alpha_{total} = \alpha_{particles} + \alpha_{base\ fluid} \quad (17)$$

Where α represents a particular thermophysical property of the nanofluid under investigation.

Taking into consideration, the concentration of the nanofluid particles, Φ, the following can be written to describe the nanofluid thermal and thermophysical properties;

$$\alpha_{total} = \alpha_{base\ fluid} + \alpha_{particles.}(\Phi) \quad (18)$$

Where; Φ represents the nano particles concentration.

The following relationship was used to relate the thermal conductivity to thermal diffusivity and density of the nanofluids [7,20];

$$\lambda = \alpha\, \delta\, C_p \quad (19)$$

Where Cp is the specific heat, α is the thermal diffusivity, ʎ and ρ represent the thermal conductivity and density, respectively.

The specific heat is calculated for nanofluids as follows [31];

$$c_{pnf} = \frac{(1-\emptyset)(\rho Cp)_{bf}+\emptyset(\rho Cp)_p}{(1-\emptyset)\rho_{bf}+\emptyset\rho_p} \quad (20)$$

Where “nf” and “bf” refer to nanofluid and basic fluid, respectively. Ø is the nanofluid particle concentration. ρ represents the density.

The density of nanofluids can be written as follows [31];

$$\rho_{nf} = \emptyset_p\rho_p + (1-\emptyset)\rho_{bf} \quad (21)$$

Other thermophysical properties of nanofluids such as thermal conductivity, and thermal diffusivity can be calcualted using equations (17) through (21). Interested readers in the calculation of thermophysical properties of nanofluids are advised to consult references [11, 20-31].

It is worthwhile mentioning that equations (7) through (16) are coupled with equations (17) through (21) in order to determine the characteristics of the heat transfer fluid HTF using nanofluids.

The efficiency of the solar PV panelscan be expressed as follows;

$$\eta_{pv} = \frac{Q_{elec}}{Q_{colector}} \quad (22)$$

Where, Q_{elec} is calcualted by equation (4) and,$Q_{colector}$ is obtained by equation (5).

The thermal efficiency of thermal energy transferred to the heat transfer fluid HTF is;

$$\eta_{Qth} = \frac{Q_{th}}{Q_{colector}} \quad (23)$$

Where $Q_{th}$is calcualted by equation (16).

Finally, the hybrid system energy conversion efficiency for harnessing energy from solar energy using of photovoltaic-thermal solar panel and nanofluids can be formulated as;

$$\eta_{sh} = \frac{Q_{th}+Q_{elec}}{Q_{colector}} \quad (24)$$

Where, Q_{elec} is calcualted by equation (4).Q_{th} is calcualted by equation (16).

NUMERICAL PROCEDURE

The model describing the energy conversion and heat transfer mechanisms taking place during energy conversion process heat in the PV-Thermal solar panels new concept with nanofluids has been presented in equations (1) through (24). The aforementioned equations have been solved as per the logical flow diagram shown in Figure.2, where the input independent and dependent parameters are defined for the PV-Thermalsolar panel, thermal tubes, nano particles; AI2O3, CuO, Fe304 and SiO2 and heat transfer fluid. These equations were integrated in the finite-difference formulations. Iterations were performed until a solution is reached with acceptable iteration error. The numerical procedure starts with the use of the solar radiation to calculate the mass flow water circulating in the thin parallel tubes that are welded to the backside of photovoltaic PV solar panel. This follows by predicting the base fluid and nanofluids and their thermophysical properties as well as the heat transfer characteristics at different concentrations of nano particles, circulating in the PV-Thermal solar panel heat tubes/ exchanger using the finite difference formulation. Finally, the individual and hybrid system efficiencies were calcualted.

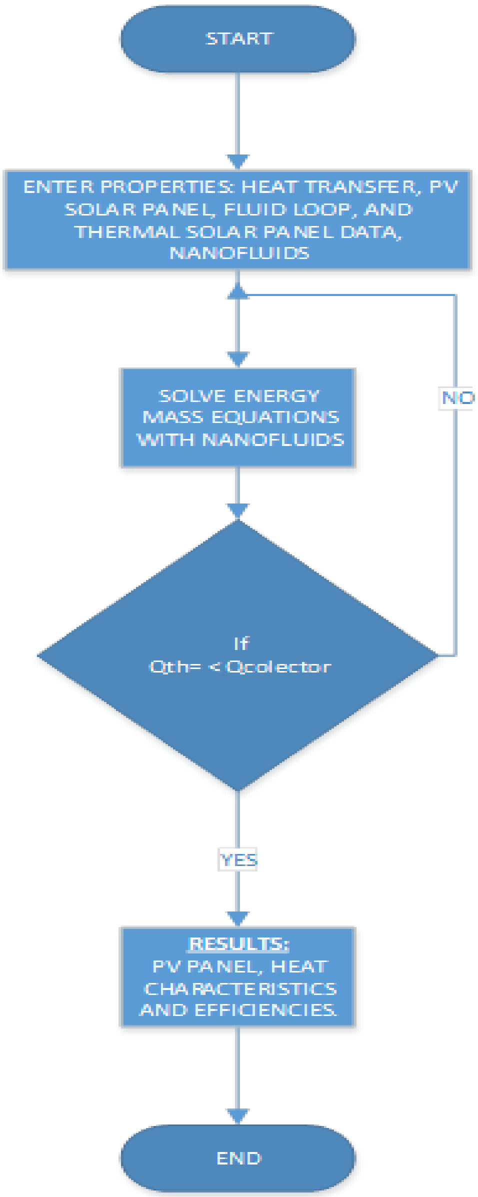

Figure. 2 Logical flow diagram for finite difference scheme.

DISCUSION AND ANALYSIS:

The aforementioned system of equations (1) through (24) have been coded in finite-difference forms, integrated and numerically solved as per the logical diagram in Figure.2. Samples of the predicted results for the PV-Thermal solar panel, thermal heat dissipated by the PV solar panel and absorbed by heat transfer fluid HTF using various nano particles; AI2O3, CuO, Fe304 and CiO2as well as comparison between the different nanofluids are presented at different inlet conditions hereby. In the following sections, we also present the analysis and discussions of the numerical results predicted as well as the validations of the proposed simulation model. The simulations were performed for temperature difference across the thermal tubes welded to the back of the PV solar panel of 5, 10, 15, 20 and 25 °C. However, only the results of the temperature difference of 15 °C across the thermal tube will be presented and analyzed hereby. It is worthwhile noting that the numerical simulation presented was performed under different conditions such as; PV cell temperatures from 10°C through 70°C, ambient temperatures from 10°C through 38°C and solar radiations; 550, 750, 1000 and 1200 w/m^2.

The PV solar panel characteristics under consideration in this study are obtained from Faragali et al. [17]. The characteristic curves of the PV solar panel are also obtained from in the manufacturer’s specification sheet [17].The PV panel parameters used in this study are; Total surface area of the PV module (SP) is 0.617 m2, Total surface area of cells in module (Sc) is 0.5625 m2, module efficiency 12% at reference temperature (298 K), overall absorption coefficient is 0.73, and Temperature coefficient is 0.0045 K-1. Interested readers in the full disclosure of the range values of the other parameters are advised to consult Faragali et al. [17].

It is also assumed in this simulation that the whole panel is covered in PV cells, with no packing material is used to fill in gaps between the cells on a panel. The PV cells are commercial grade monocrystalline silicon cells with electrical efficiency of 12%, and have a thermal coefficient, of 0.54% [1/K] [17]. The thermal coefficient represents the degradation of PV cell output per degree of temperature increase. The cooling thermal tubes/heat exchanger pipes are bonded to the back of the PV solar model without any air gap to ensure complete heat transfer by conduction, convection and radiation to the fluid transfer fluid (HTF) with nanofluids flowing in the thermal tubes.

In order to solve equations (1) through (24), the thermal and thermophysical properties of the nano particles AI2O3, CuO, Fe304 and SiO2 were obtained from references;[20], [26], [29] and references[31, 35]. In particular, Allen [26] studied the magnetic field enhancement of thermal conductivity of magnetic nanofluids and calculated the thermal conductivity from the measured temperature difference for each nanofluids such as AI2O3, CuO, Fe304 and SIO2 at different magnetic fields. His data at zero magnetic fieldamong the other aforementioned references were considered for this study.

In general, it is quite clear from figures (3) through (18) constructed under solar radiation for the different nanofluids that the thermal heat dissipated by the PV solar panel and absorbed the heat transfer fluid and PV-Thermal solar panel efficiencies are significantly influenced by the concentrations of the injected nano particles, the nanofluid flow rates and the type of material of the nano particles as well as the thermophysical properties of each particular nanofluids under investigation.

In the following sections, we present the simulations and analysis of the predicted resultsof thermal heat dissipated by the PV solar panel and PV-Thermal solar panel efficiencies under nanofluid flows from 0,00697 kg/s to 0.0345 kg/s, nano particles volumetric concentrations from 0.01 to 0.5 and under solar radiations from 550 $W/m^2$to 1200 W/m^2. It should also be noted that the design of the thermal tubes welded to the back of the PV solar panel was based upon mass flow rate of 0.00697 kg/s at550 W/m^2 solar radiation.

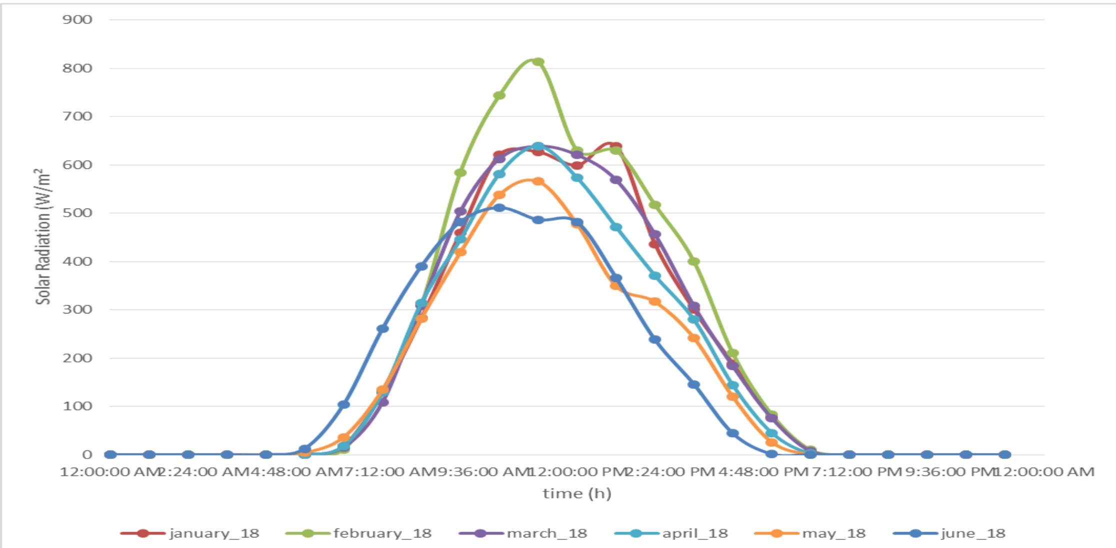

Figure.3 Time variation of solar intensity W/m^2, 2018.

Figures 3 presents a typical solar isolation profiles at the site for various months of the year 2018 at different hours of the day. It is quite apparent that the peak solar irradiation and maximum temperatures occur at midday. However, average solar irradiations were used in the modeling and simulation of the Photovoltaic panels. The recording of the ambient conditions such as temperature, relative humidity and wind speed during the same period showed that the relative humidity is stable during the various hours of the day. Therefore, in the simulation of the PV-thermal solar panel, the relative humilities were assumed constant.

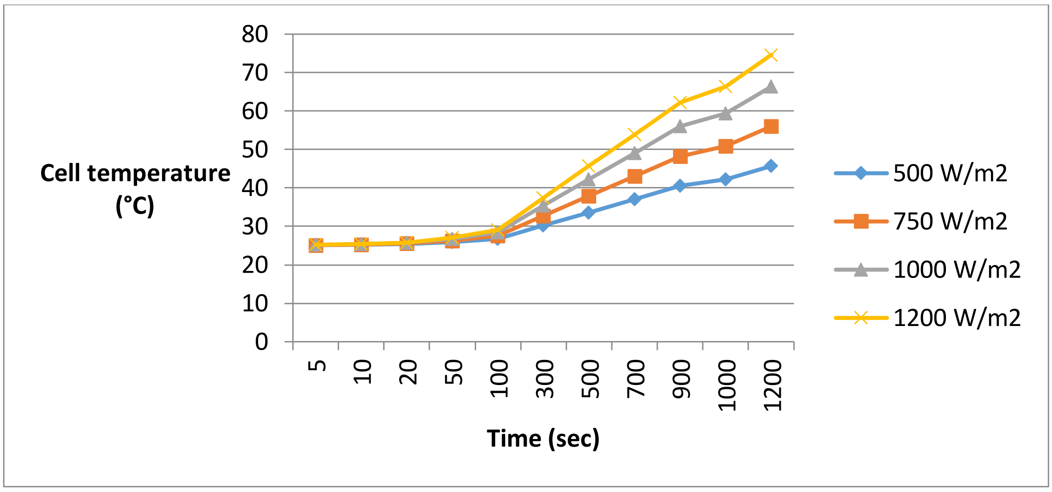

Figure.4 PV Cell temperature at different solar radiations and temperature difference 15 °C [11]

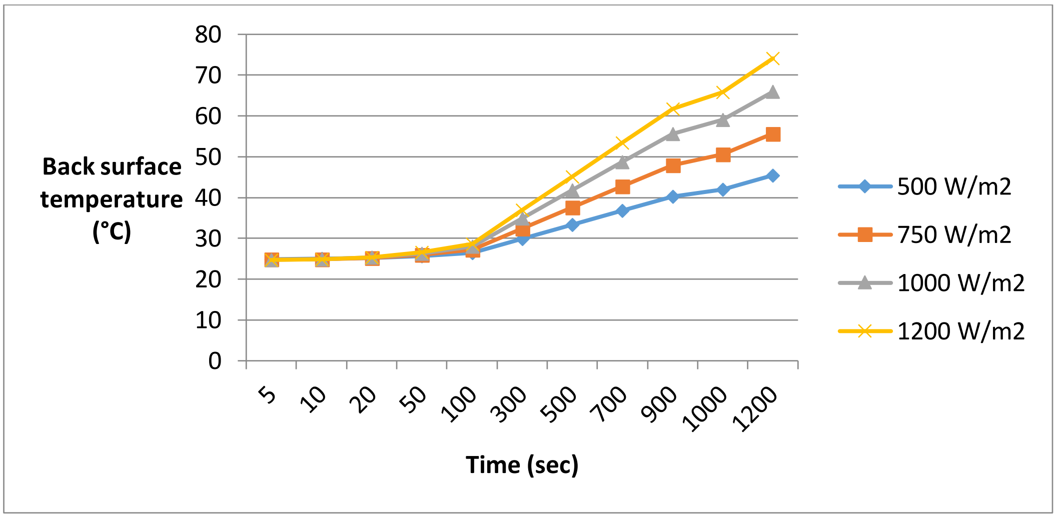

Figure.5 Back PV Cell temperature at different solar radiations and heat exchanger temperature difference 15 °C [11].

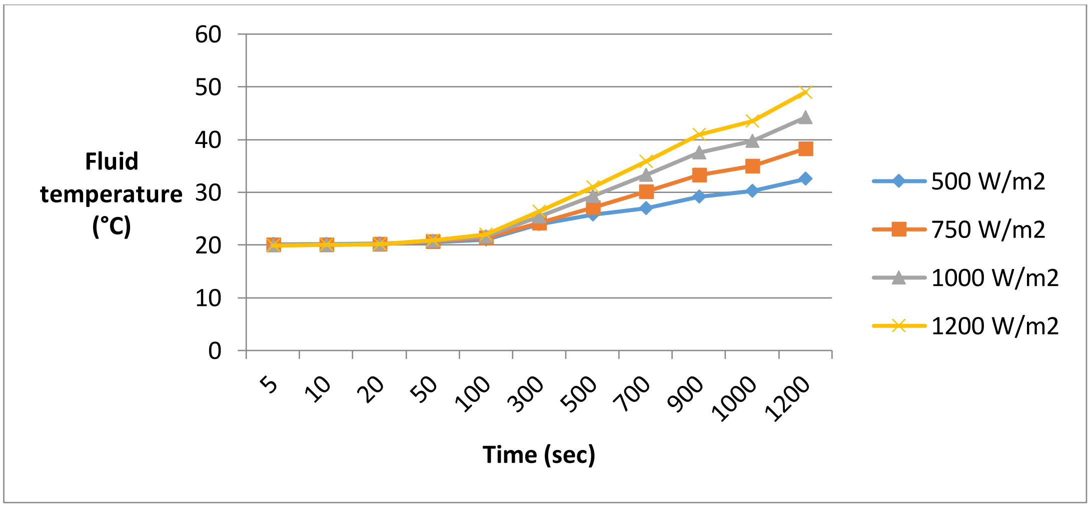

Figure.6 Fluid temperature exiting the thermal pipes at heat exchanger temperature difference 15 °C [11].

The dynamic behavior of the important and critical key temperatures in PV solar panel analysis; PV cell, PV back and fluid temperatures have been presented in Figures 4 through 6, at different solar radiations with water used as the base heat transfer fluid in the thin parallel thermal tubes welded on the backside of photovoltaic solar panel. Furthermore, equations (6) through (16), show clearly that an increase in the PV cell temperature will result in an increase in the back-cell temperature and consequently the fluid temperature due to the heat transfer from solar energy by conduction and convection as well as radiation, respectively. Consequently, this increases the thermal heat absorbed by the heat transfer fluid. In additions, the aforementioned figures also show that the higher the solar radiation the higher the PV cell temperature, the PV back temperature and the heat transfer fluid temperature. It can also be noted that the PV solar panel cell temperature reaches its maximum design temperature after 1200 seconds depending upon the solar radiation [11].

The figures 4 through 6 clearly support the aforementioned statement that the higher the PV cell temperature the higher the back cell and the higher fluid temperatures as well as the thermal energy transferred to the heat transfer fluid [11]. It is quite evident from the results presented in these figures that the cell temperatures increase with the increase of solar radiation. This can be interpreted as per equations (5) and (6), where the higher the solar radiations the higher the energy absorbed by the PV cell and consequently the higher the temperature of the PV cell until reaches the design temperature. This has been reported and discussed in the literature where similar observations were presented in references [11] through [17].

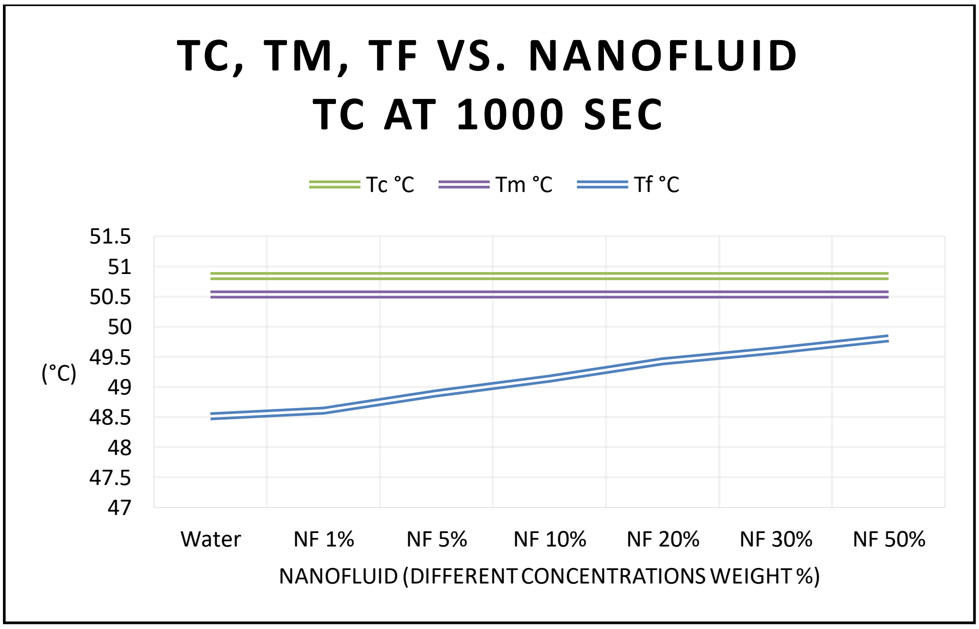

Figure 7. Temperatures at different concentrations of Nanofluid AI2O3and 750 w/m^2

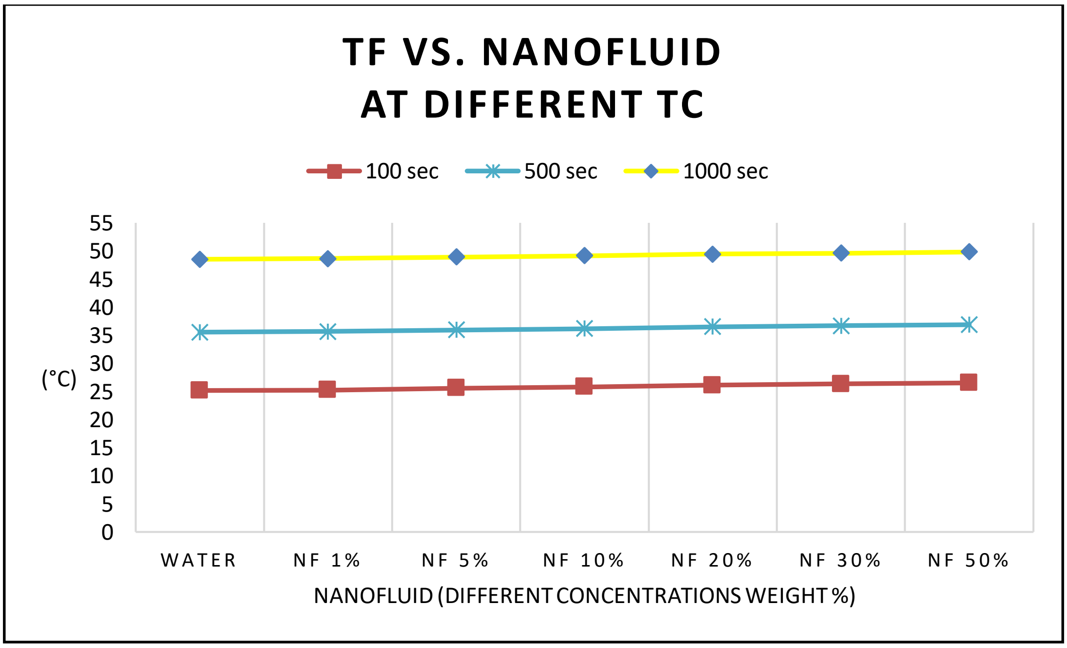

Figure 8. Temperatures $T_f$at different concentrations of Nanofluid AI2O3at 750 w/m^2

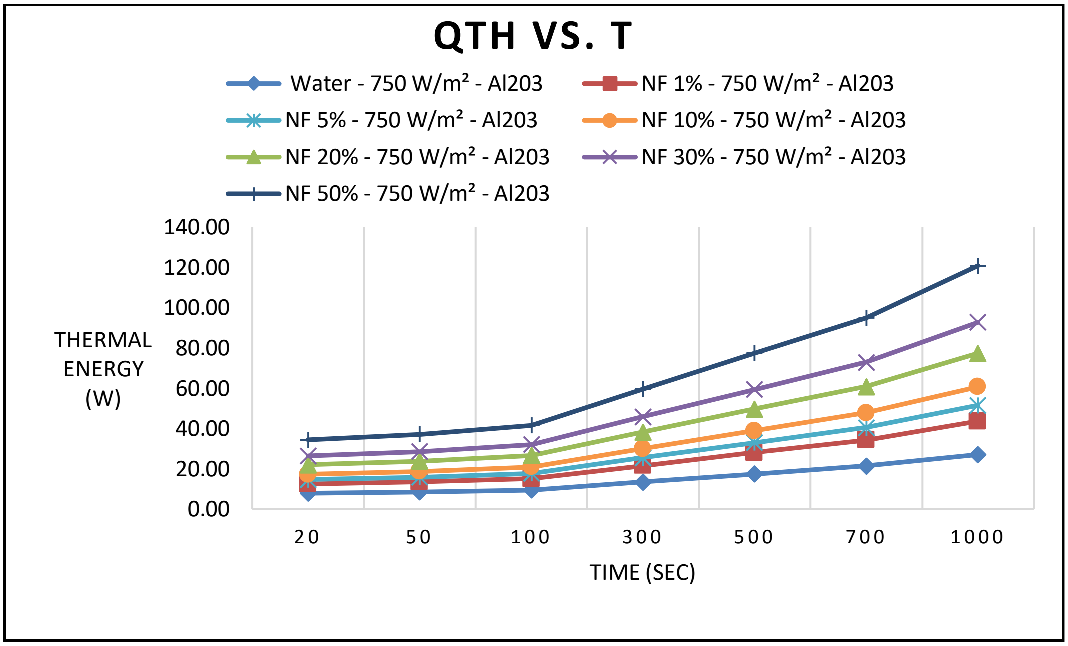

Figure 9. Qthat different Tc and concentrations of Nanofluid AI2O3 at 750 w/m^2

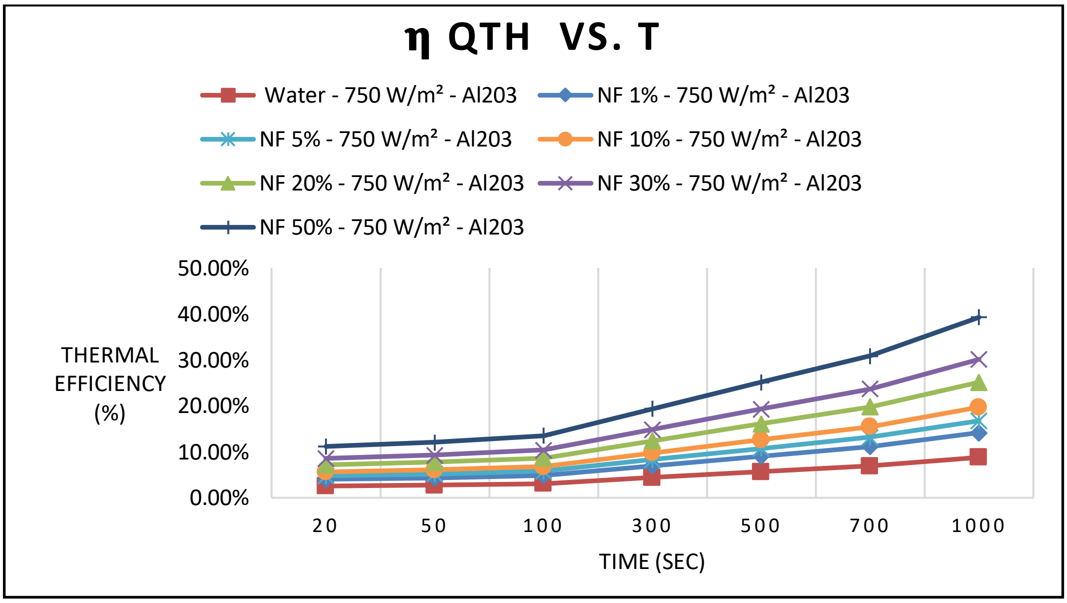

Figure 10. Efficiency of Qth at different Time and concentrations of Nanofluid AI2O3 at 750 w/m^2

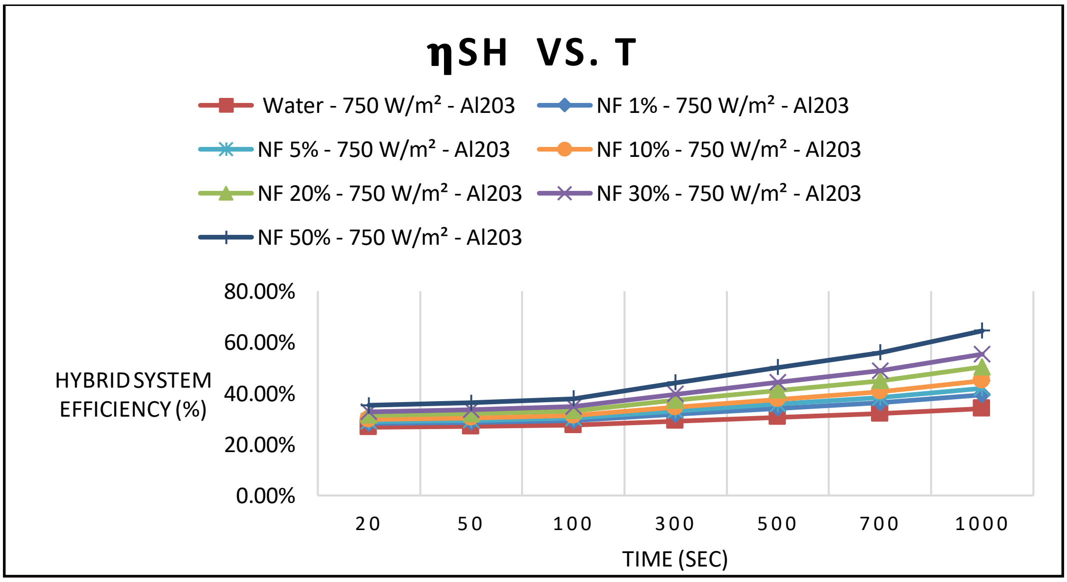

Figure 11. Hybrid system efficiency at different Time and concentrations of Nanofluid AiO2 at 750 w/m^2

The dynamic characteristics of the nanofluid AI2O3 under different concentrations, and solar radiation 750 w/m^{2}have been presented in Figures 7 through 11. The thermal energy is calculated by equation (12) and the thermal and hybrid efficiencies are calculated by equations (23) and (24), respectively. Inaddition, the PV efficiency is calculated using equation (22).In particular, Figure .12 shows the time-variations of the PV solar panel efficiency at solar radiation 750 w/m^{2}and various nanofluid concentrations of AIO2. It is quite evident from data displayed in this figure and aforementioned figures that the existence of nanofluids in the heat transfer fluid significantly contributed to the enhancement of the key critical parameters of the PV-Thermal hybrid system in question; thermal energy dissipated from the PV panel, thermal and hybrid efficiencies over that of the water flow as base fluid.

As expected, Figure. 7 clearly shows that the higher the nanofluid concentration the higher the heat transfer fluid temperature. However, it can be noticed that the PV cell temperature and PV panel back temperature are uninfluenced by the concentration of the nanofluids. These two temperatures are only significantly impacted by the solar radiations.

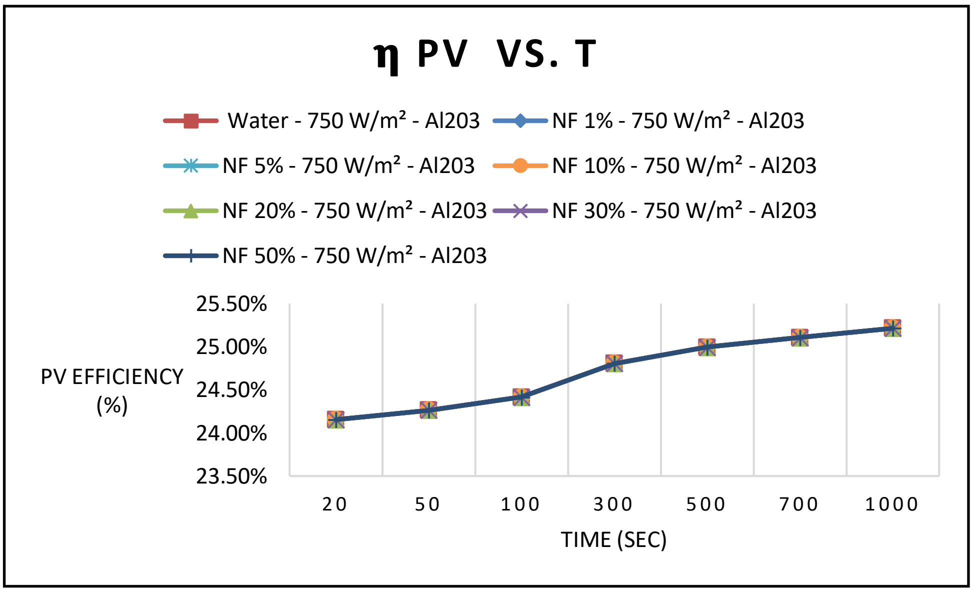

Figure 12. Solar PV panel efficiency at different Time and concentrations of Nanofluid AIO2 at 750 w/m^2

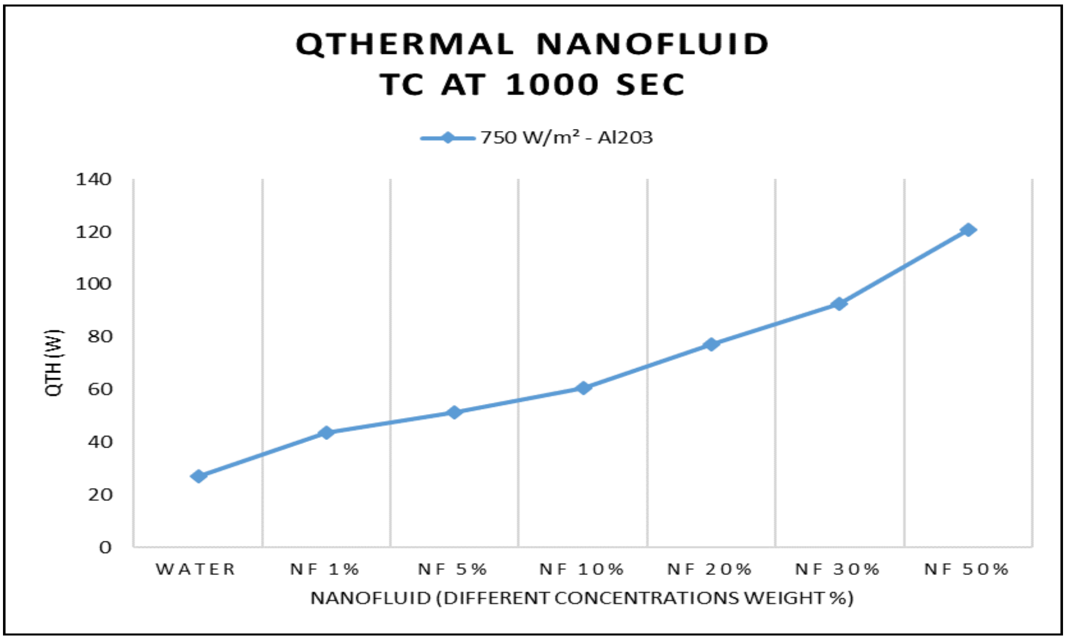

Figure 13. Solar PV panel thermal energy at different concentrations of Nanofluid AIO2 at 750 w/m^2

On the other hand, the numerical results presented in Figure .12 show that the solar PV panel efficiency at different time and concentrations of Nanofluid AIO2 at 750 w/m^2. It can be noticed from the data presented in this figure that the solar PV efficiency is quasi-constant and does not experience significant variations with time. As expected, the PV solar panel efficiency is independent of the concentration of the nanofluids and depends only on the solar PV panel characteristics and solar radiations at the site.

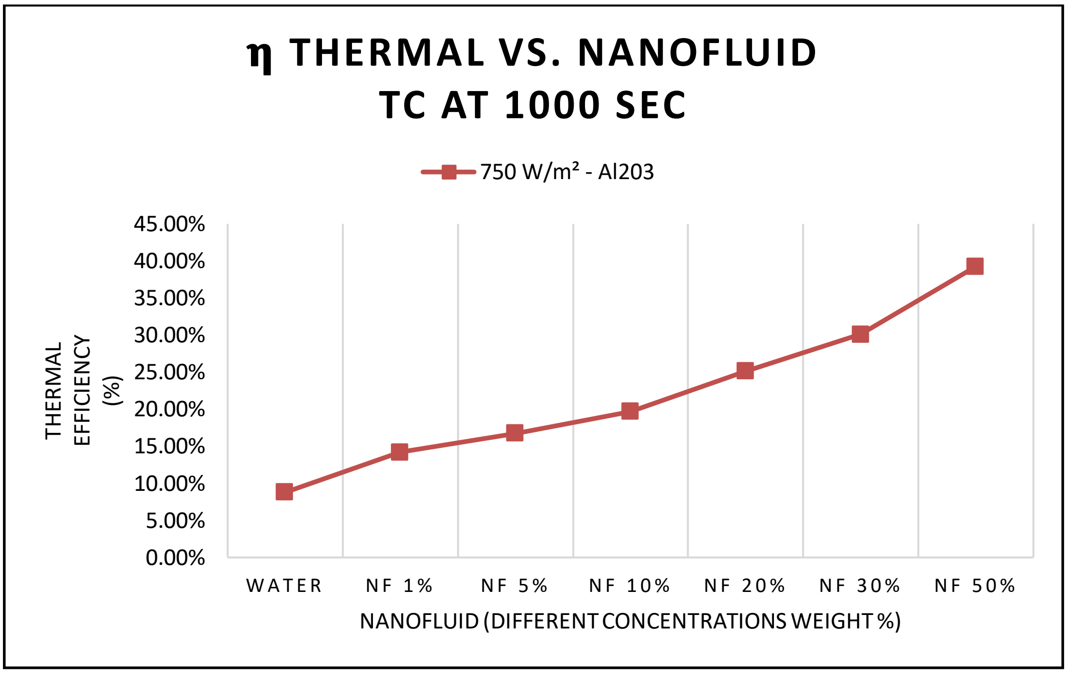

Figure 14. Thermal Solar PV panel efficiency at different concentrations of Nanofluid AIO203 at 750 w/m^2.

The impact of the nanofluid AIO203 concentrations on the thermal heat transferred from the back of the PV solar panel to the heat transfer fluid is demonstrated in Figures. 9 and 13. Where the simulated results clearly show that the higher the nanofluid’s concentration the higher the thermal heat transferred over the one transferred to the water as base fluid. This figure also demonstrates the benefits of using nanofluids in enhancing the thermal heat recovered from the PV solar panels.The enhancement of the critical parameters of the PV-Thermal hybrid system with other nanofluids other than AIO203 will be discussed elsewhere in the paper.

The thermal and hybrid system efficiencies are presented in Figures 14 and 15, respectively. It is evident from the results presented in these figures that the higher the nanofluid’s concentration the higher the thermal PV efficiency and the hybrid system efficiency over that of the water as base heat transfer fluid.

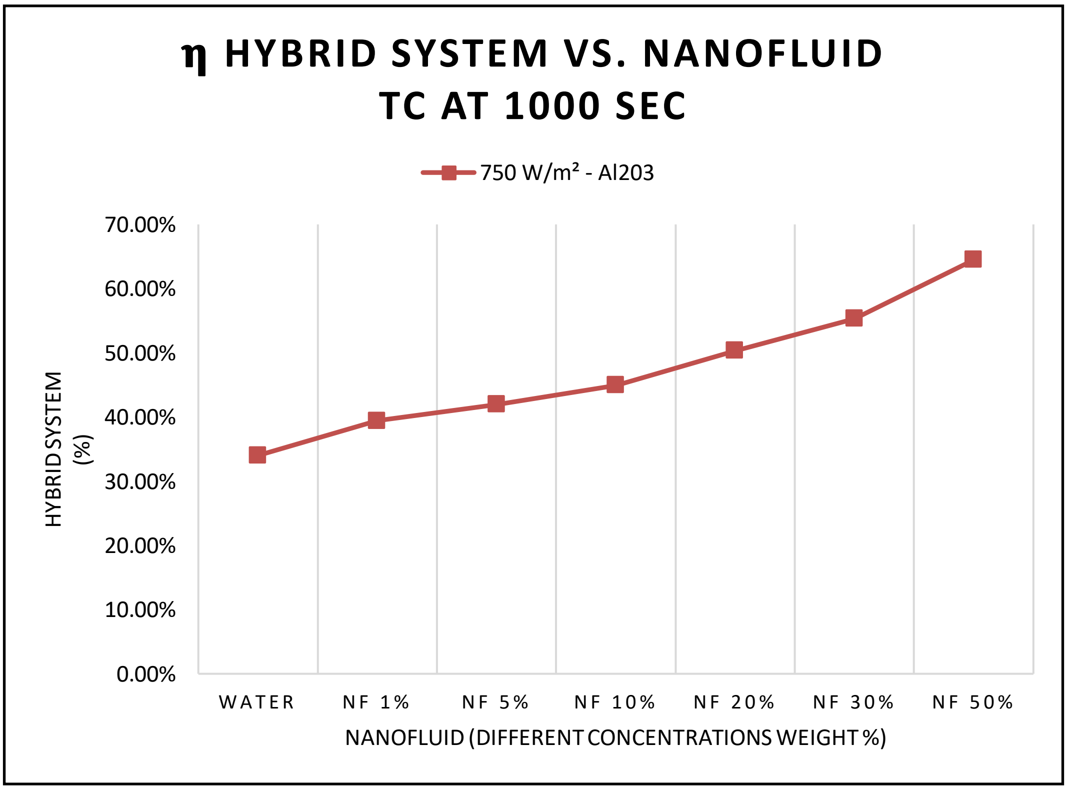

Figure 15. Solar PV panel efficiency at different concentrations of Nanofluid AIO203 at 750 w/m^2

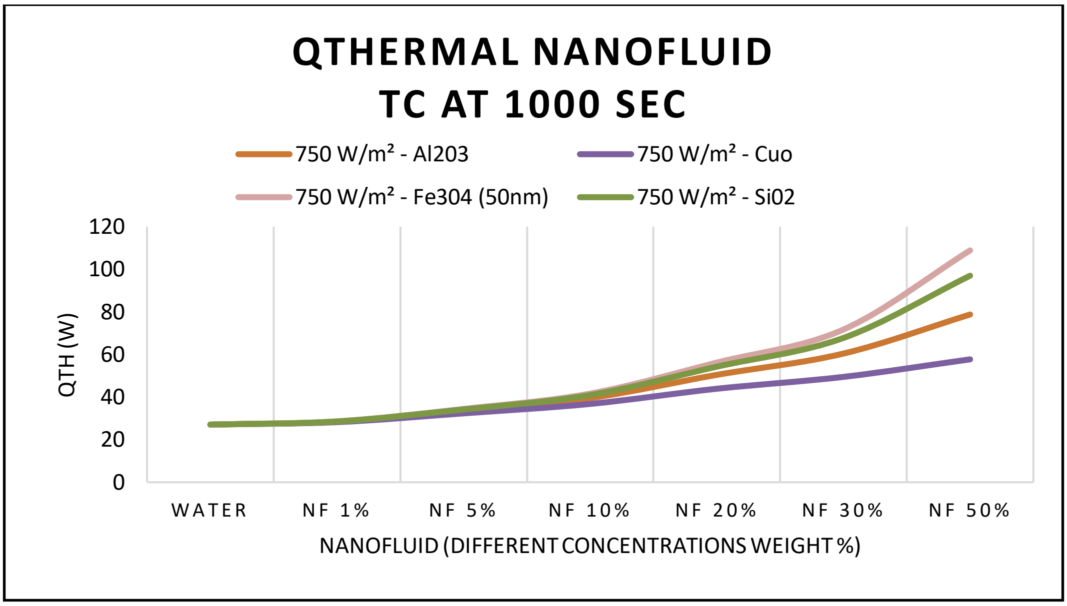

Figure 16. Solar PV panel thermal energy at different nanofluids at 750 w/m^2

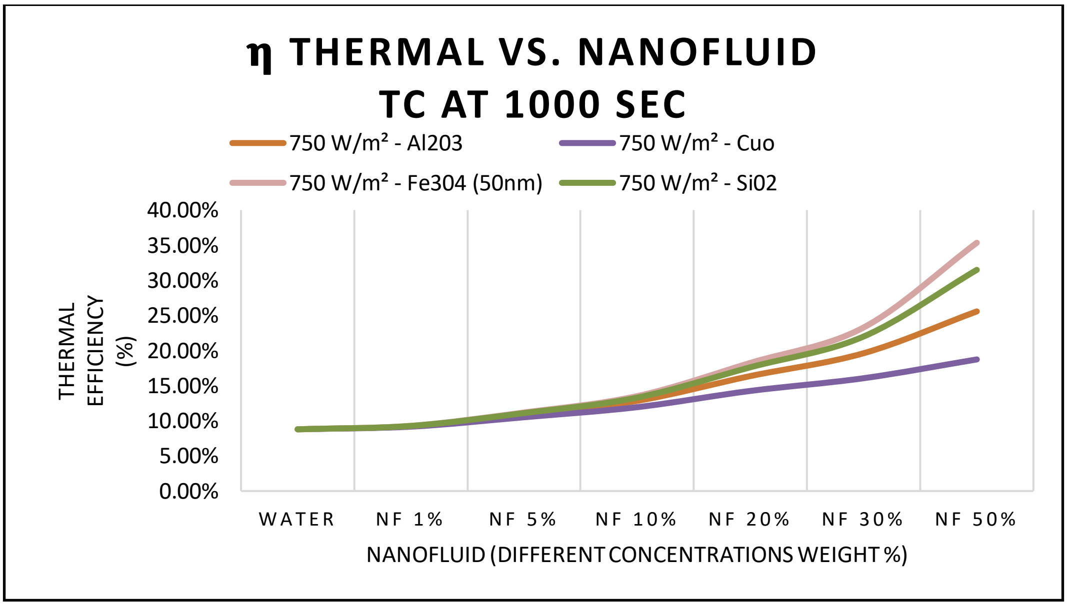

Figure 17. Solar PV panel thermal efficiency at different Nanofluids at 750 w/m^2

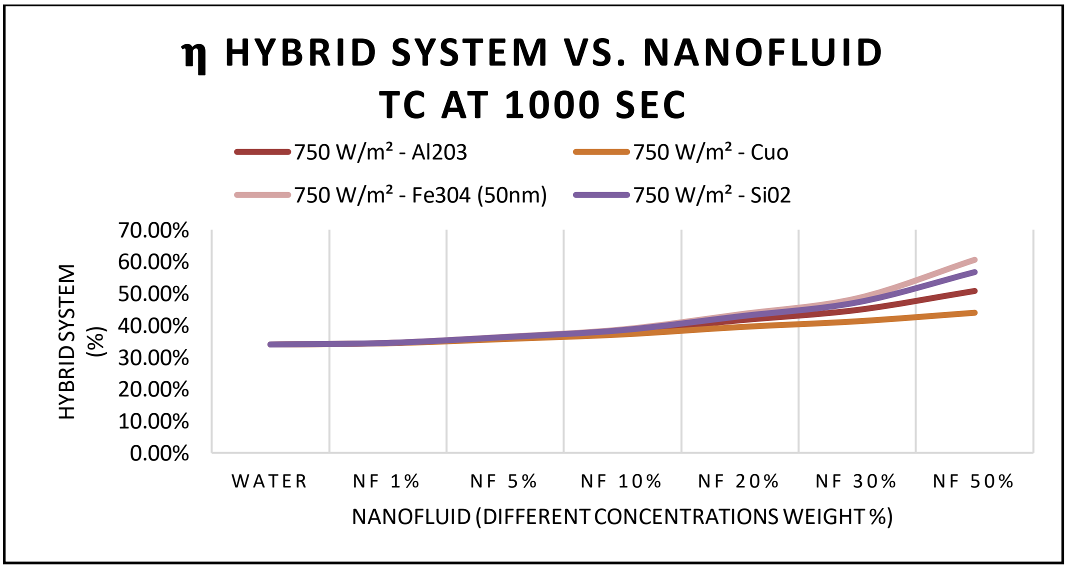

Figure 18. Solar PV panel hybrid efficiency at different concentrations of Nanofluids at 750 w/m^2

Figures 16 through 18 display the impact of using different nanofluids suspended particles of the AIO203, CuO, Fe304 and SIO2 with concentration that varies between 0.01 to 0.50at solar radiation of 750 w/m^2 with PV solar cell temperature calcualted at 1000 seconds, on the solar PV thermal energy released, thermal efficiency and hybrid system efficiency, respectively. It is quite clear from the numerical values presented in these figures that the thermal heat released by the PV solar panel to the nanofluid flow increases as the concentration of the nanofluid particles increases over the water as basic heat transfer fluid. In our opinion, this is attributed to the fact that higher nano particle concentrations increase the thermal, thermophysical and heat transfer properties of the heat transfer fluid such as specific heat, density, thermal conductivity and viscosity as well as the convection heat transfer coefficient. That increase stimulates and drives more heat transfer energy released from the PV solar panel into the heat transfer fluid circulating in the heat tubes welded to the back of the PV solar panel. It is also worthwhile noting that the PV solar panel output power and PV solar panel efficiency remain constant and is fully independent of the nanofluids concentrations.

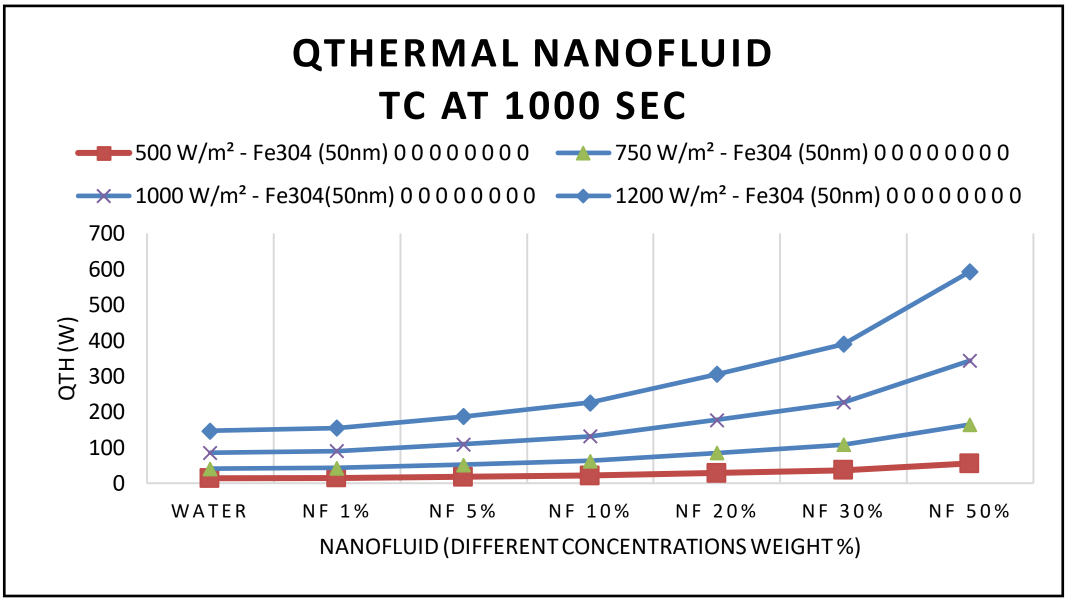

Figure 19. Solar PV panel thermal heat released at different solar radiations and concentrations of Nanofluid Fe304.

On the other hand, Figure 19, demonstrates clearly the impact of the solar radiation on the thermal heat released from the PV solar panel into the heat transfer fluid with PV cell temperature calculated after at 1000 seconds using nanofluid Fe304. The results displayed in this figure clearly show that the higher the solar radiation the higher the thermal heat released from the PV solar panel to the heat transfer fluid. It is also obvious from this figure that the higher the nanofluid concentration the higher the thermal heat released over the water as basic working fluid.

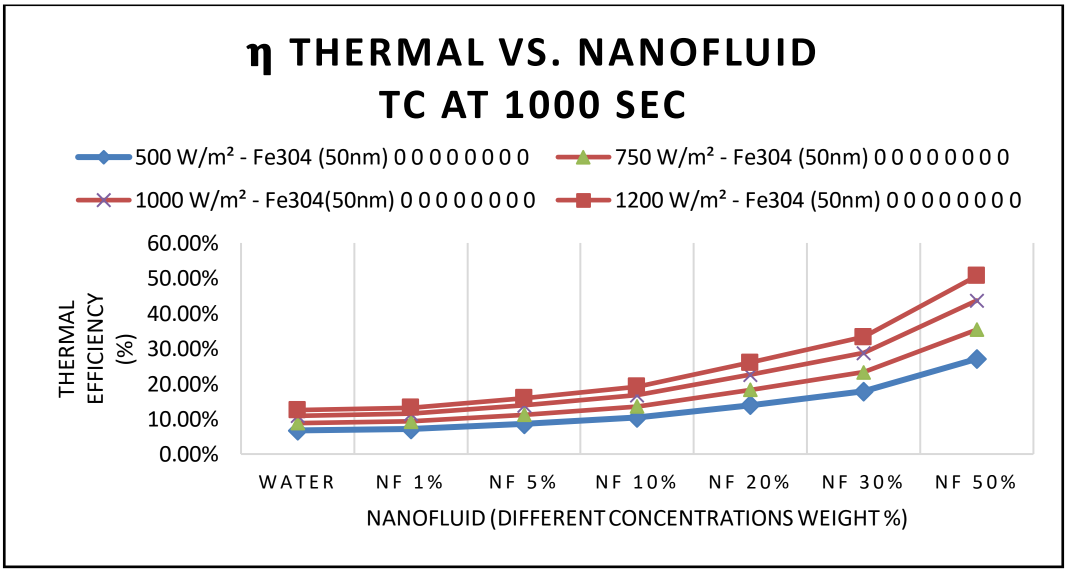

Figure 20. Solar PV panel thermal efficiency at different solar radiations and concentrations of Nanofluid Fe304

Furthermore, the heat released by the PV solar panel and absorbed by the heat transfer fluid as well as the thermal and hybrid efficiencies of the PV-Thermal solar panel, are displayed in Figures 20, through Figure 24 for solar radiation of 750 w/m2. These values are calculated by equations (12) and (22) through (23), respectively, with suspended particles of the AIO2, CuO, Fe304 and SIO2 at concentrations vary between 0.01 to 0.50. It is quite evident from the numerical results shown in particularly Figure 22 that the thermal heat released by the PV solar panel were significantly higher with the use of nanofluid Fe304 and they increase as the concentration of the nanofluid particles increases over the water as basic heat transfer flow. It is also believed that this is attributed to the higher thermophysical and thermodynamic as well as heat transfer properties of nanofluid Fe304 compared to the other nanofluids under investigation.

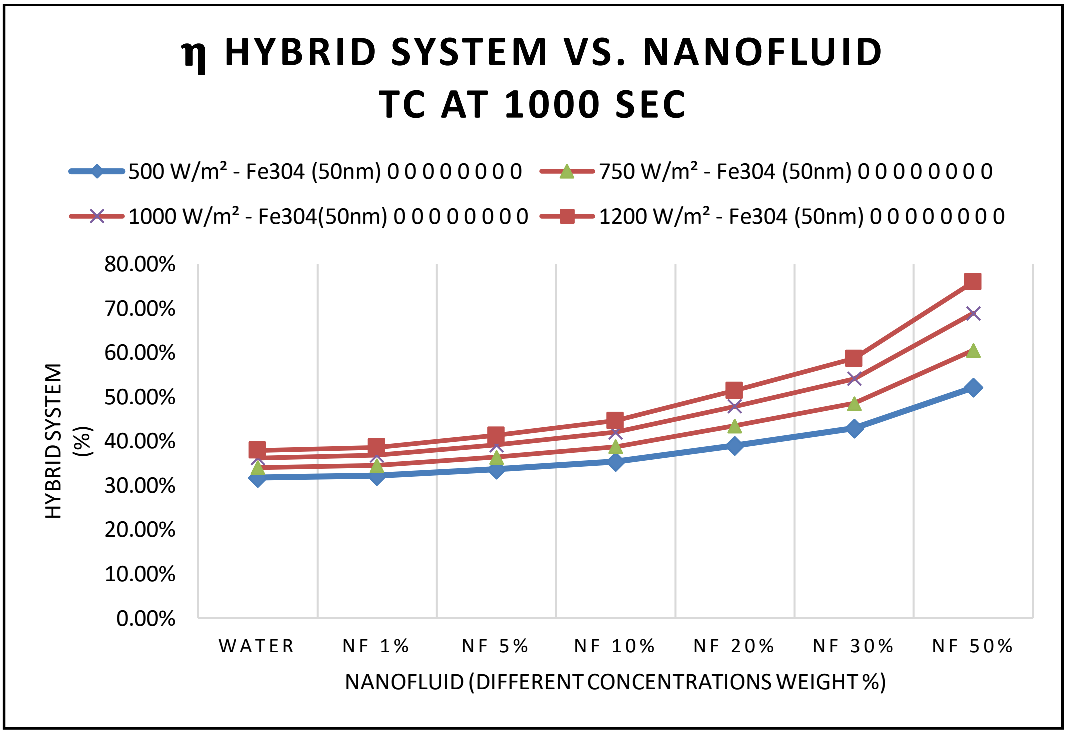

Figure 21. Solar PV panel hybrid system efficiency at different solar radiations and concentrations of Nanofluids.

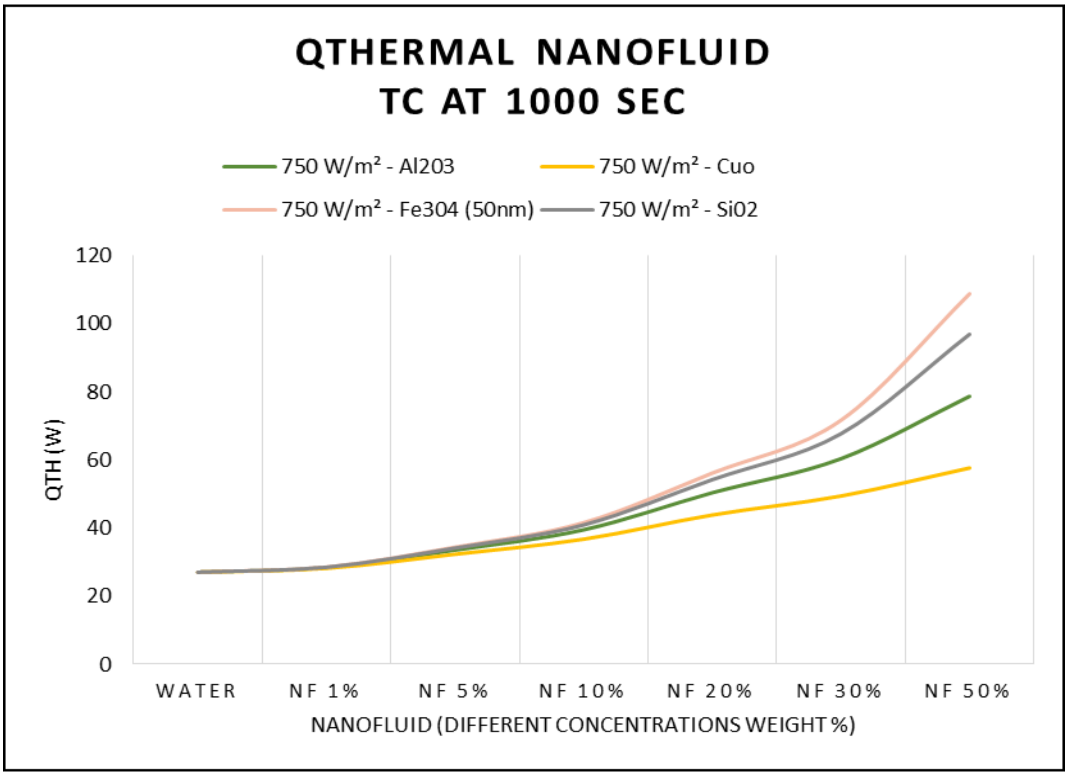

Figure 22. Solar PV thermal heat released panel thermal at different concentrations of Nanofluids

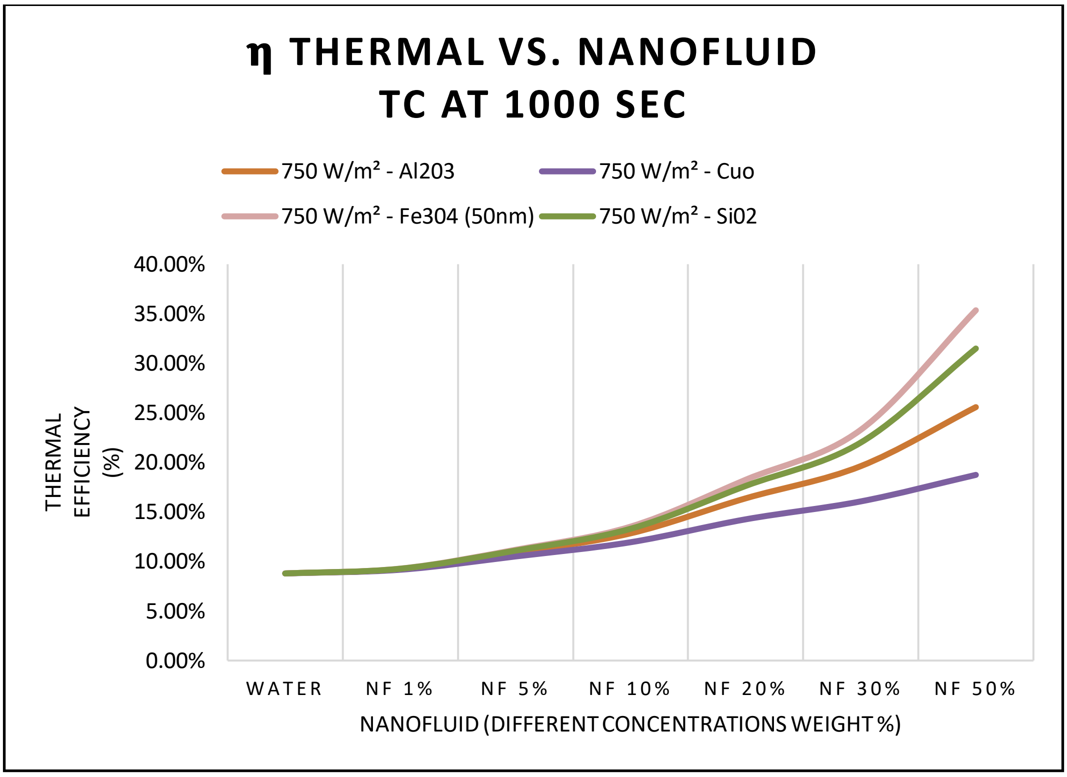

Figure 23. Solar PV thermal efficiency at different concentrations of Nanofluids

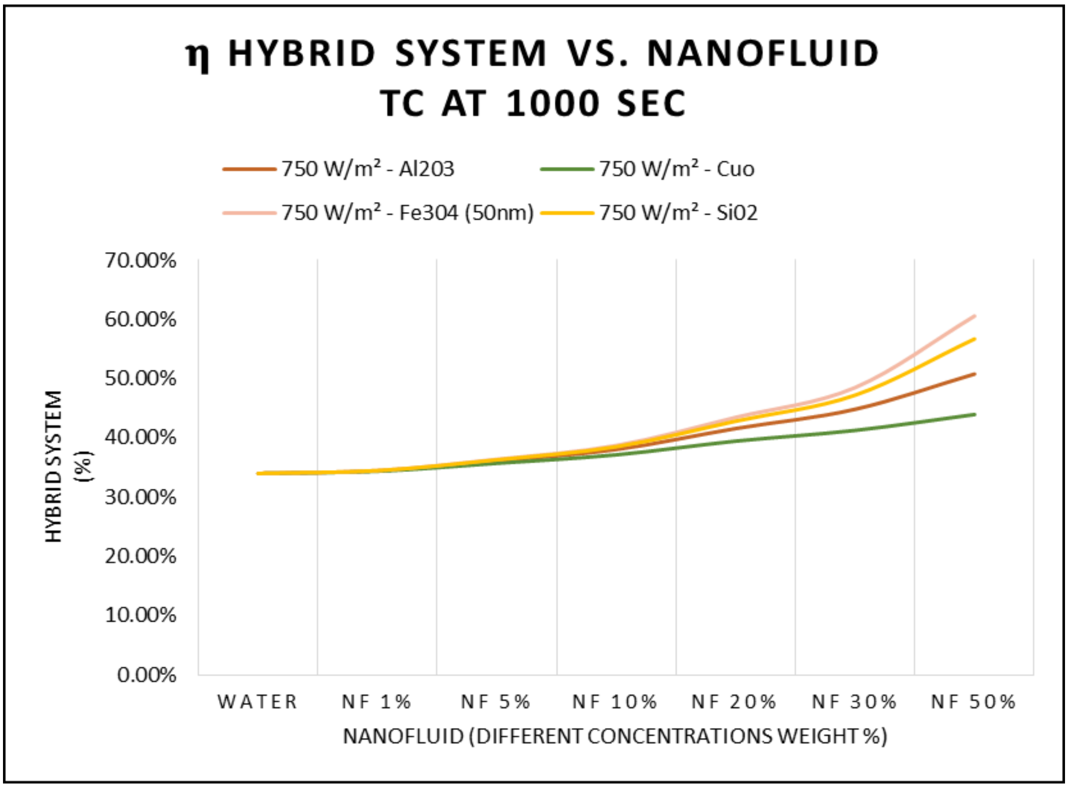

Figure 24. Solar PV hybrid efficiency at different concentrations of Nanofluids

On the other hand, the numerical results displayed in Figures 23 and 24, gave also evidence that the thermal and hybrid efficiencies at 750 w/m^{2}solar radiations were enhanced by the use of nanofluid Fe304 over the basic fluid, water. As previously indicated, this is also attributed to the fact that higher nano particle Fe304 concentrations increase the thermodynamic, thermophysical properties and heat transfer properties of the HTF and that in turn stimulates and drives the heat transfer from the solar radiation into the fluid transfer fluid circulating in the heat tubes welded to the back of the PV solar panel. Furthermore, it can also be pointed out that at the low concentration of 1% there is no noticeable difference between the nano particles of the AI2O3, Fe304, CuO, and SiO2 on the impact on the thermal heat absorbed by the heat transfer fluid. However, at nano particle concentrations higher than 10%,it is quite evident that Fe304 and other naofluids have the greatest impact on the amount of thermal heat absorbed and efficiencies. This trend as shown in the aforementioned figures continued under higher nano fluid concentration.

Furthermore, the study reported by Maiga et al., [37] on fully developed turbulent flow of Al2O3- water nanofluid flow in circular tube at uniform heat flux clearly confirms our findings that the inclusion of nano particles into the base fluids has produced a considerable augmentation of the heat transfer coefficient, thermal heat transferred and that clearly increases with an increase of the particle concentration as per Figures 22 through 24. Where adding nanofluids enhanced the thermal energy transferred to the heat transfer fluid as well as thermal and hybrid efficiencies over that of the water as base fluid. This is also in agreement with what has been reported in the literature namely; inreferences [31] through [34].

The dynamic profile of the evolution at different time steps of the mass flow rate with the water as the base fluid and other nanofluids is presented in Figure .25. The data in this figure was depicted at 500 w/m^{2}solar radiation for PV solar panel at different concentrations of Nanofluid Fe304. It is evident from the results presented in this figure that the mass flow rate circulating in the heat tubes welded to the back of the PV solar panels stabilizes after 1000 seconds. Similar results were observed for the other nanofluids under investigation. On the other hand, results displayed in Figure .26 clearly illustrate that the thermal heat dissipated from the PV solar panel and absorbed by the heat transfer fluid with nanofluid Fe304 increases with the increase of the mass flow rate at different concentrations of the nanofluid, Fe304.Again, similar observations were observed with the other nanofluids under investigation.

Ones of the most frequent nanofluids studied in the literature are the Fe304 and AI2O3. The dynamic behavior at different time steps of the thermal heat released by the PV solar panels against the mass flow rate for these two nanofluids is depicted in Figure.27 and 28, respectively for 500 W/m^2 and 50% nanofluids concentration. As can be seen from the results displayed in Figures.27, and 28 that at this particular concentration of nanofluid Fe304 or AI2O3, the higher the mass flow rate of the heat transfer fluid the higher the thermal energy dissipated and absorbed by the heat transfer fluid. Consequently, the thermal efficiency and hybrid efficiency have the highest values at the higher heat transfer fluid flow. Therefore, it is quite significant and critical for the PV-Thermal solar panel collector concept presented in this research work to be designed at the optimum heat transfer flow as well as the optimum solar radiation in order to ensure higher thermal heat transferred and also the higher thermal and the hybrid efficiencies, respectively.

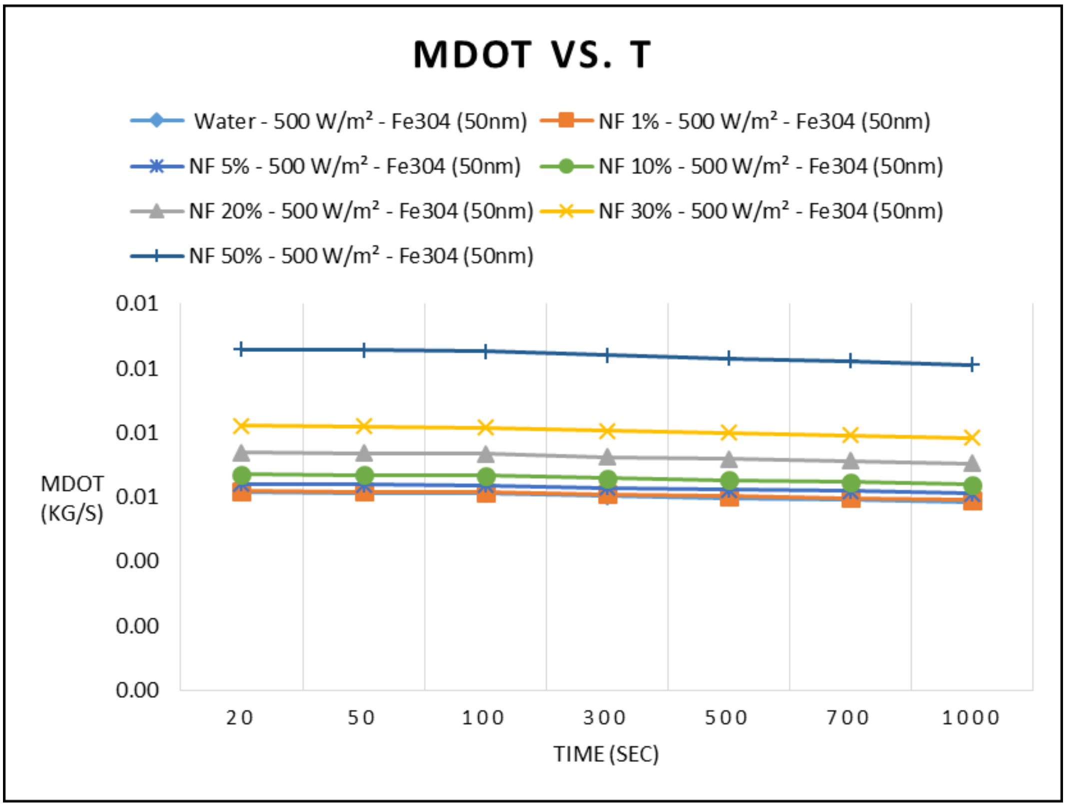

Figure 25. Solar PV mass flow rate at different concentrations of Nanofluid Fe304

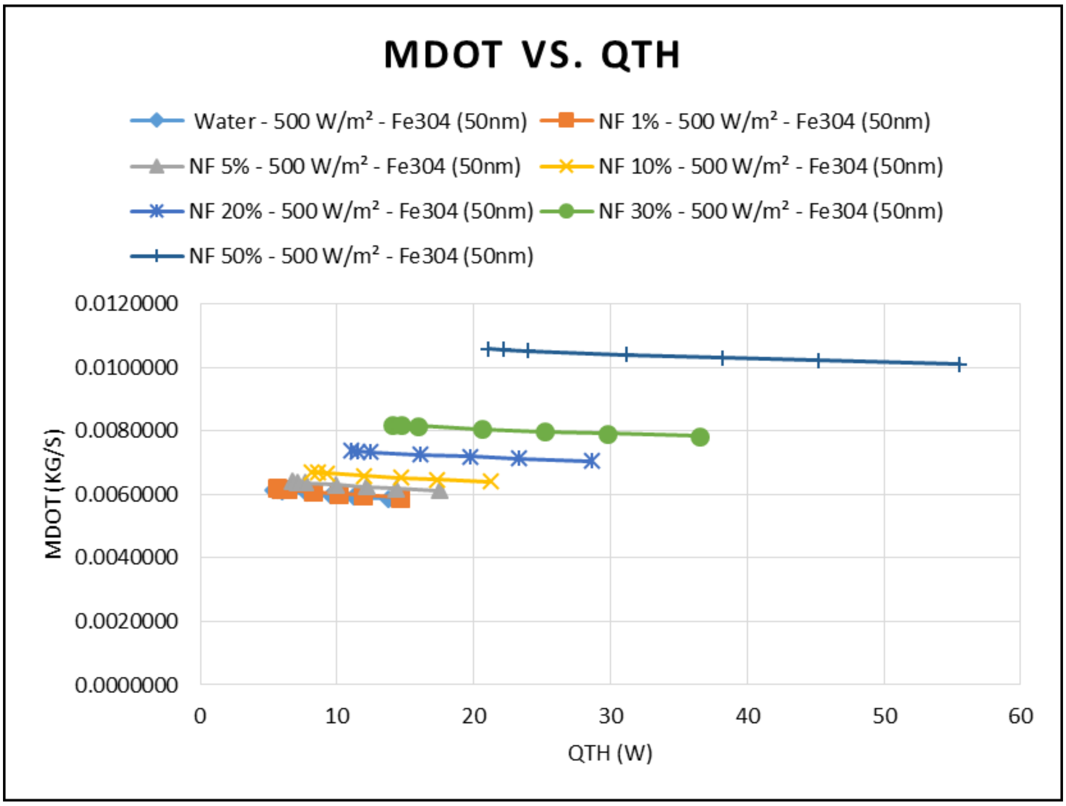

Figure 26. Solar PV mass flow rate versus thermal energy released at different concentrations of Nanofluid Fe304

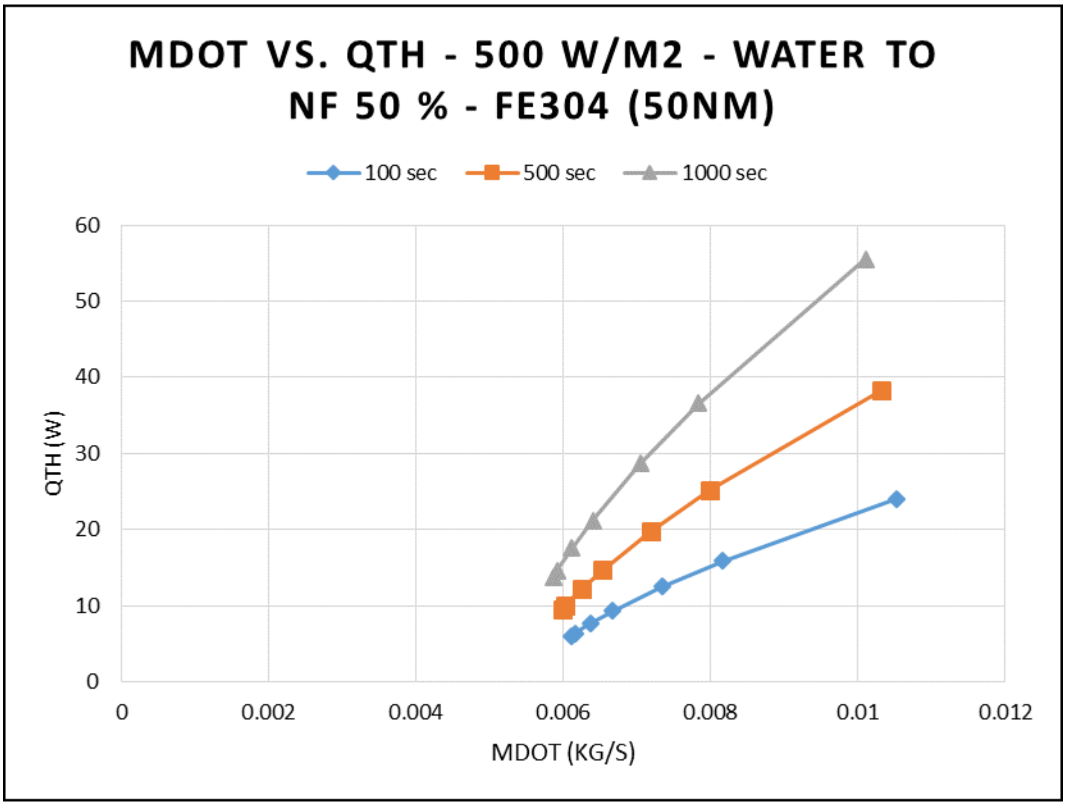

Figure 27. Solar PV mass flow rate versus thermal energy released at 50% concentration of Fe304Nanofluid

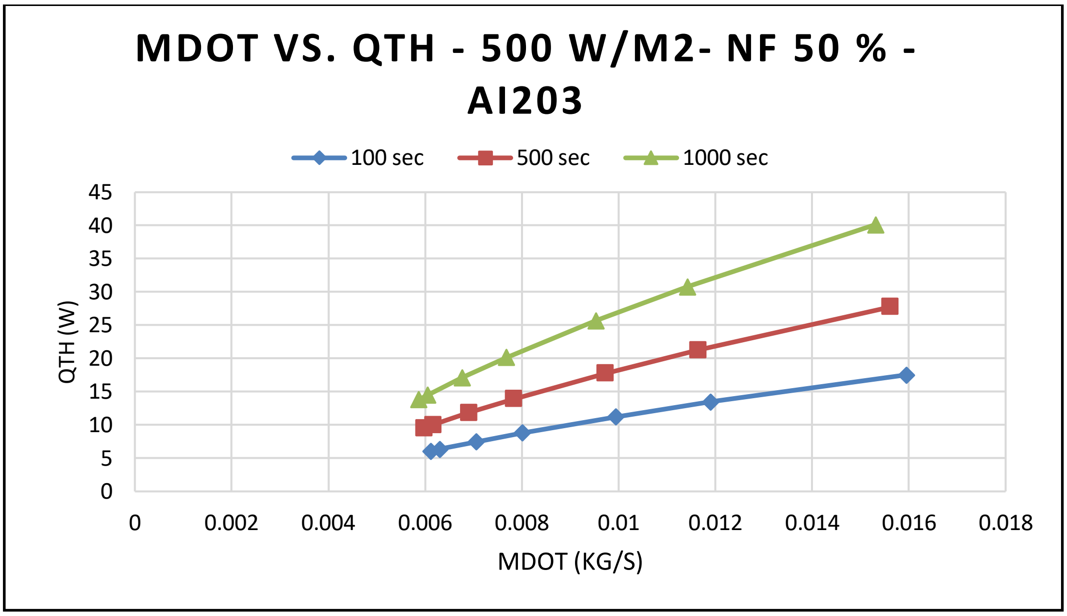

Figure 28. Solar PV mass flow rate versus thermal energy released at 50% concentration of AI2O3 Nanofluid

Model validation

This section is intended to validate the prediction of the numerical model describing the PV-Thermal novel hybrid system using nanofluid sunder investigation and presented in equations (1) through (29). Since the model in question is based and an extension of the PV solar panel model and no data was available in the literature on the new proposed concept presented hereby, it was decided to use only data available in the literature on the solar PV panel and related characteristics for comparison. In the following sections, we discuss the model validation and present the different comparisons. In additions, it was felt that the validation of the PV solar model should give immense confidence in the results presented hereby. Therefore, we have constructed Figures 29and 30 to compare the proposed model prediction of the PV solar panel characteristics and the data presented in the literature on the solar PV namely, references [9, 17, and 30].

In particular, as shown in Figure 29, it is quite apparent from the comparison presented in this figure that the model prediction fairly compares with the data of the dynamic PV cell temperature presented by Faragali et al. [17]. The comparison presented in this figure also showed that the model and data have the same trend, however, some discrepancies exit. It is believed that the discrepancies are due to the fact that the various parameters used in equations (6) through (9) were not reported by Faragali et al. [17] and therefore, Rajapakse et al. [30] had to be consulted for those parameters. However, same observations were reported in references [8, 12, and 17], therefore, we feel that our model fairly predicted the PV cell dynamic profile.

In addition, Figure 30 compares between the model prediction of the power generated by the PV solar panel and the experimental data of references [17] and [30], where the PV solar power and amperage are displayed. It is evident form this figure that our model prediction compares well with experimental data available in the literature [17 and 30].

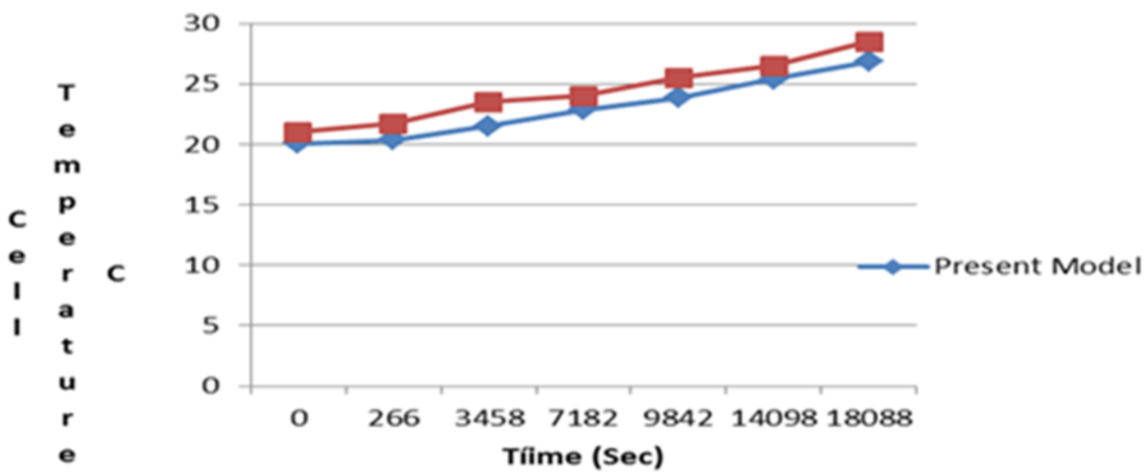

Figure 29. Comparison between model prediction and experimental data [17, 20, 33]

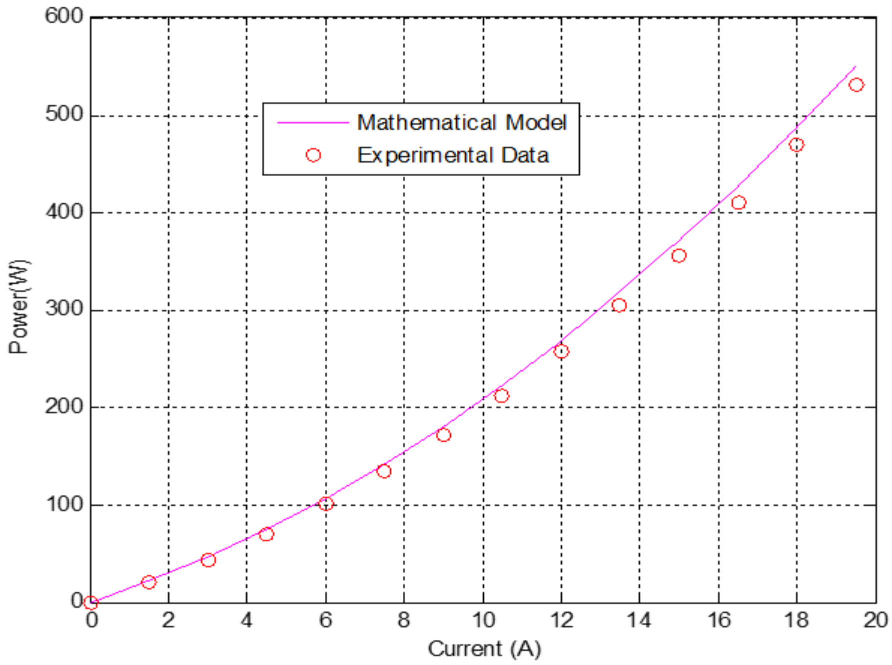

Figure 30. Comparison between model and experimental data [17, 30]

CONCLUSIONS

During the course of this study, the characteristics of heat transfer fluid with nano particles AI2O3, CuO, Fe304 and SIO2 circulating in PV-Thermal solar panel thermal tubes/heat exchanger welded to the back of the PV solar panel have been modeled, presented, analyzed and compared to data published in the literature. The numerical model presented hereby was established after the mass and energy conservation equations coupled with the heat transfer equations of the heat transfer fluid (HTF) using nano particles; AI2O3, CuO, Fe304 and SIO2 with concentration vary from 1 through 50 %.Thermodynamic, thermophysical and heart transfer properties of the nanofluids were obtained from the available data in the literature. The numerical resulted presented hereby showed that the higher the nano particles concentration the higher the thermal heat absorbed and released by the PV solar panel to the heat transfer fluid (HTF). In addition, results also showed that a higher nanofluid mass flow rate increases the thermal heat released by the PV solar panel. Furthermore, it was also shown that increasing the nano particles concentration enhanced the heat transfer properties and consequently increased the heat transferred and thermal heat absorbed by the heat transfer fluid, this in turn enhances the thermal efficiency of the PV-Thermal solar panel and the hybrid efficiency of the solar panel. In addition, numerical results also showed that the nanofluid Fe304 has the highest thermal heat transfer to HTF and the highest thermal and hybrid efficiencies.

Finally, the simulated results of our numerical model presented hereby fairly predicted the PV solar panel characteristics and compared well with other data reported in the literature.

NOMENCLATURE

A_{Panel}, Area of solar panel (m^2)
A_f, Flow area (m^2)
C_{pw}, Specific heat of water (kJ/(kg K))
D_H, Hydraulic diameter (m)
G, Radiation (W/m^2)
h, Heat transfer coefficient
K_w, Thermal conductivity of water (kJ/(ms°C))
l, Tube length (m)
m_w, Water mass flow rate (kg/s)
N: number finite different element (N: 1-12)
Q_{tub}, Heat (kJ)
R, Tube radius (m)
$T_{(water)\_m}$), Temperature of HTF at "m" element (°C)

Greek

ρ_w, Density of water flow (kg/m^3)
μ, Water viscosity (m^2/s)

Subscripts

Qth	Thermal heat
pv	PV solar panel
nf	Nanofluid
sh	Hybrid system
w	HTF
Tub	Tube
w	Water

ACKNOWLEDGEMENT

The research work presented in this paper was made possible through the support of the Catholic University of Cuenca. The author greatly appreciates the efforts of Edwin Marin in the lengthy calculations using finite difference formulation.

REFERENCES

1. Dai, N, Li, S., Zhang, Z, (2017), Simulation of Hybrid Photovoltaic Solar Assisted Loop Heat Pipe/Heat Pump System, Appl. Sci, 7, 2-15, 2017.
2. Tripanagnostopoulos et al, (2002) “Hybrid photovoltaic/thermal solar systems. Sol Energy”, 72, PP 217–34.
3. Bergene, O M Lovvik, (1995), “Model calculations on a flat-plate solar Heat-collector with integrated solar cells”, Solar Energy, 55, PP 453–62.
4. H.G. Teo, P.S. Lee, and M.N.A. Hawlader, (2012), An active cooling system for photovoltaic modules, Applied Energy 90 (2012) 309-315.
5. Hashim, H, Bomphrey, J.J., Min, G., (2016),”Model for Geometry Optimization of Thermoelectric Devices in a Hybrid PV/TE System”, Renewable Energy, 87, 458-463, 2016.
6. H.P. Garge, R.K.Agarwal, (1995), “Some aspects of a PV/T collector/force Circulation flat-plate solar water heater with solar cells”, Energ Convers Manage, 36, PP 87–99.
7. Endalew, A., K., (2011),” Numerical modeling and experimental validation of heat pipes solar collector for water heating”, KTH Industrial Engineering and Management, Sweden, Master thesis ED1-2011-128MSC 2011.
8. Sandnes, J. Rekstad, (2002),”A photovoltaic/thermal (PV/T) collector with a polymer absorber plate, experimental study and analytical model”, Sol.Energy 2002;72: PP 63–73.
9. Zhao, X. (2003), “Investigation of a novel heat pipe collector/CHP system”. Nottingham University, England, PhD 2003.
10. Liang, R., Zhang, J., and Zhou, C., (2015), “Dynamic simulation of novel solar heating system based on hybrid photovoltaic /thermal collectors (PVT), Procedia Engineering, 121, 675-682, 2015.
11. S.Sami and C. Campoverde; (2018), Dynamic simulation and modeling of a novel combined hybrid photovoltaic-thermal panel hybrid system, International Journal of Sustainable Energy and Environmental Research 2018 Vol. 7, No. 1, pp. 1-23
12. S. Sami, (2018); “Modeling and Simulation of a Novel Combined Solar Photovoltaic-Thermal Panel and Heat Pump Hybrid System”, Clean Technol. 2018, 1, 89-113; doi:10.3390/cleantechnol1010007
13. Sami, S. and Marin, E. (2017), “Simulation of Solar Photovoltaic, Biomass Gas Turbine and District Heating Hybrid System”, International Journal of Sustainable Energy and Environmental Research, IJSEER, Vol. 6, No. 1, p 9-26, 2017.
14. Sami, S. and Rivera, J. (2017), “A Predictive Numerical Model for Analyzing Performance of Solar Photovoltaic, Geothermal Hybrid System for Electricity Generation and District Heating”, Science Journal Energy Engineering, SJEE, Volume 5, Issue 1, p 13-30, 2017.
15. Sami, S. and Marin, E. (2017),"A Numerical Model for Predicting Performance of Solar Photovoltaic, Biomass and CHP Hybrid system for Electricity Generation", IJESRT, International Journal of Engineering Sciences & Research Technology, Volume 4, Issue 1, p 1- 22, 2017.
16. Good, C., Chen, J., Dai, Y and Hestnes, A.G, (2015), “Hybrid Photovoltaic-Thermal system: A Review. Energieprocedia, 70, 683-690, 2015.
17. Faragali, H., M., Fahmy, F.H. and Hassan, M.A., (2008), “A Simulation Model for Predicting the Performance of PV/Wind- Powered Geothermal Space Heating System in Egypt”, The Online Journal on Electronics and Electrical Engineering (OJEEE), Vol.2, No.4.
18. G. Pei, Fu, H. Zhang and T. Jie “A numerical and experimental study on a heat pipe PV/T system”, Solar Energy 85(5):911-921, (2011).
19. S. Sami and Marin, E., (2018), “Dynamic modeling and simulation of hybrid solar photovoltaic and PEMFC fuel power system”, RA Journal of Applied Research, V. 4, Issue 5, pp; 1664-1683, 2018.
20. S. Sami, (2018); Impact of magnetic field on the enhancement of performance of thermal solar collectors using nanofluids, International Journal of Ambient Energy, DOI: 10.1080/01430750.2018.1437561
21. Sagadevan, S.,(2015) A review ofrole of Nanofuids for solar Energy Applications, American Journal of Nano Research and Applications, Vol. 3, No.3, p 53-61. 2015.
22. Chaudhari, K, S, and Walke, P.V., (2014) Applications of NanoFluid in Solar Energy- A Review, International Journal of Engineering Research & Technology, IJERT, Vol.3, Issue 3, p 460-463, 2014
23. Kaseian, A, Eshghi, A. T. and Sameti, (2015) A Review on the Applications of Nanofluids in Solar Energy Systems, Renewable and Sustainable Energy Reviews, Vol.43, p. 584-598, 2015.
24. Saleh, A, M., (2012), Modeling of Flat-Plate Solar Collector Operation in Transient States, MsE Thesis, Purdue University, Fort Wayne, Indiana, 2012.
25. Choi, U.S., (1995), Enhancing Thermal Conductivity of Fluids with Nanoparticles, ASME FED 231, p 99-103, 1995.
26. Allen, C., (2105), Magnetic Field Enhancement Thermal Conductivity Analysis of Magnetic Nanofluids, MScE, University of Texas at Arlington, 2015.
27. Nerella, S, Sudheer, N., and Bhramara, P.(2014), Enhancement of heat Transferby Nanofluids in

Solar Collectors, International Journal of Innovations in Engineering and Technology, IJIET, Volume 3, No 4, 2014.

28. Bachock, N, and Pop, I, (2012), Flow and Heat Transfer Characteristics on a Moving Plate in a Nanofluid, International Journal of Heat and mass Transfer, Vol.55, p. 642-648, 2012.
29. Kakac, S., and Pramuan, J., (2009), Review of Convective Heat Transfer Enhancement with Nanofluids, International Journal of heat Transfer, Vol 52, p.3187-3196, 2009.
30. Sagadevan, S., (2015), A Review on Role of Nanofluids for Solar Energy Applications, American Journal of Nano Research and Applications, Vol 3, No 3, p. 53-61. 2015.
31. K.V. Sharma, Akilu Suleiman, Hj. Suhaimi B. Hassan and Gurumurthy Hegde, (2017), “Considerations on the Thermophysical Properties of Nanofluids”,Engineering Applications of Nanotechnology, Topics in Mining, Metallurgy and Materials Engineering, DOI 10.1007/978-3-319-29761-3_2
32. Taylor, R.A, Phelan, P.E, Qtanicar, T., Walker, C.A., Nguyen, M., Timble, S. and Prasher, R., (2011), Applicability of nanofluids in high Flux Solar Collectors, Renew Sustain Energy, Vol 3: 0231104, 2011.
33. Sami, S., (2018);”Enhancement of Performance of Thermal Solar Collectors Using Nanofluids” International Journal of Energy and Power Engineering. Special Issue: Green Hybrid Systems for Power Generation in Remote Zones Non-Connected to Grid. Vol. 7, No. 1-1, 2018, pp. 1-8.
34. Khullar,V., Tyagi,H, Phelan, P.E, Qtanicar, T.,Singh, H. and Taylor, R.A.(2013), Solar Energy Harvesting using Nanofluids-based Concentrating Solar Collector, Journal of Nanotech Enf Med, Vol 3, No 3,, 031003(9p), 2013
35. Azo Material, http://www.azom.com/properties.aspx
36. Brenner, H, Edwards, D.A. and Wasan, D.T., (1993), Interfacial Transport Process and Rheology, Butterworth, New York, USA, 1993.
37. S.E.B. Maiga, S.J. Palm, C.T. Nguyen, G. Roy, N. Galanis, Heat transfer enhancement by using nanofluids in forced convection flows. Int. J. Heat Fluid Flow, 26 (2005) 530 - 546.