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Effect of solar radiations on the Performance of Heat Pipes Driven by Magnetized Nanofluids

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Abstract — *The effect of solar radiation on the behavior of heat pipes under magnetized nanofluids has been described by a two-dimensional dynamic heat transfer and fluid flow model using solar photovoltaic-Thermal collector under different boundary conditions. The model has been established after the equations of conservation of mass and energy, thermodynamic thermophysical properties under different magnetic Gauss forces. Model validations were made against literature data. The predicted results were fairly compared with existing data on the subject.*

Keywords: *Numerical modeling, simulation, photovoltaic-thermal solar hybrid system, heat pipes magnetized nanofluids, model validation.*

I. Introduction

In-depth knowledge of the thermal and thermophysical properties such as thermal conductivity, specific heat, and viscosity, can influence the heat transfer from solar radiations to nanofluids. [1-5]. Nanofluids have excellent thermal conductivity [1-11] were applied as the working fluids of traditional heat pipes applications to enhance thermal performance. The thermal conductivity of magnetized nanofluids increases with the volumetric concentration percentage of magnetic particles with increasing the magnetic field strength [12-28].

In this hybrid system, the solar irradiance is converted into electrical energy in the PV'scell; the excess thermal energy generated in this process is dissipated into the water-based nanofluids. This, in turn, diminishes the cell temperatures and enhances the conversion efficiency of the cell, and enhances the combined photovoltaic-thermal efficiency of the hybrid system. Interested readers in the subject can consult references [12-53].

Yang [12] studied the heat transfer coefficient of the heat pipe and its use in solar energy applications and the heat transfer performance of heat pipes induced by the magnetic fields and Nanofluid. The experimental results showed that the heat pipe with magnetic fluid hasa 13.9% higher performance than that of a conventional heat pipe.

References [14] by Wang et al. presented a critical review of nanofluids that are considered to be next-generation heat transfer mediums due to their excellent thermal performance. Their paper investigated "the effect of electric fields and magnetic fields on heat transfer of nanofluids and analyzed the mechanism of thermal conductivity enhancement of nanofluids, the chaotic convection, and the heat transfer enhancement of nanofluids in the presence of an applied electric field or magnetic field through the literature review. The studies presented searched showed that applied electric field and magnetic field can significantly affect the heat transfer performance of nanofluids, although there are still many different opinions about the effect and mechanism of heat transfer. Their work was intended and supposed to be useful for the researchers who endeavor to understand the research state of heat transfer of nanofluids under the influence of a magnetic field".

The use of silver nanofluid by Kang et al. [16] and Do, et al.[15] "to investigate the thermal performance of a grooved circular heat pipe and showed that the thermal resistance is decreased when compared with pure water. Do et al. [15] also experimented on the screen mesh wicked heat pipes using Al2O3nanofluids and showed that the heat pipe performance had been increased up to 40%. Yang et al. [17] showed that CuOnanofluid could improve the thermal performance of the heat pipe and also presented that an optimal mass concentration of 1.0 wt% is enough".

This paper presented a simulation model of the photovoltaic-thermal solar panel hybrid system with heat pipes that use nanofluids, ay different solar radiations, and under the influence of a magnetic field. This study uses magnetized nanofluids to enhance the energy conversion efficiency of the PV- Thermal solar hybrid system by utilizing excess thermal energy dissipated PV solar panels to activate heat pipes to produce hot water for domestic hot water (DHW) and/or thermal industrial applications under different solar radiations. The improvement of efficiency due to the combined effect of using magnetized nanofluids and solar energy usage would contribute to decreasing the environment limit on the application of the solar heater in a wide range.

II. Mathematical Model

The integrated system shown in Figure .1 is consisted of a photovoltaic solar panel and welded thin parallel tubes on its backside for the circulation of the cooling heat transport fluid with nanofluids. The parallels then tubes were soldered to the PV solar panel and connected to a thermal tank from which water-based nanofluids flow through the solar collector copper pipes and carry the excess heat away from the PV-thermal panel, as shown in Figure 1. The excess heat released by the PV solar panels was absorbed by the evaporator section of the heat pipe and released by the condenser section of the heat pipe in the thermal tank.

This hybrid system was intended for power generation by the PV solar panels and using the excess thermal heat transferred and heat pipes to produce hot water for domestic and/ or industrial use. Also, the model in question examined the enhancement in the hybrid system efficiency of the solar PV panel at various solar radiation temperatures. The model is presented in the following sections.

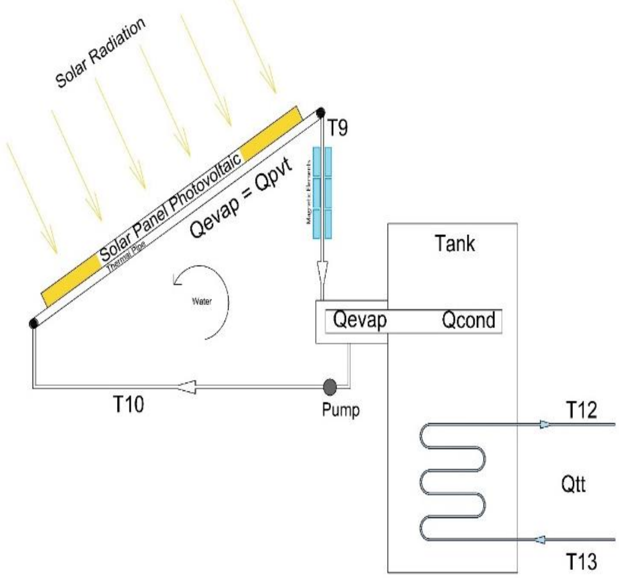

Figure 1: PV/Thermal hybrid system using nanofluids with heat pipe and magnetic field

A. PV MODEL

The solar photovoltaic panel is constructed of various modules, and each module has consisted of arrays and cells. The dynamic power output can be obtained as follows [19-23, 30];

The AC power of the inverter output of the PV solar panels circuit, 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 $cos\varphi$ as follows;

$$P(t) = \sqrt{3}\eta_{inv}V_{fn}I_o cos\varphi \quad (1)$$

Readers are advised to consult Sami [30] for further details on the calculations of the various parameters in equation (1).

B. PV THERMAL MODEL:

In the following thermal analysis, it is assumed that all PV cells behave the same; therefore, it is applied to the PV solar panel.

The heat absorbed by the PV solar cell can be calculated by the following [18-23,30];

$$Q_{in} = \alpha_{abs} G S_p \quad (2)$$

Where;

αabs: Overall absorption coefficient

G: Total Solar radiation incident on the PV module

Sp: Total area of the PV module

Meanwhile, the PV cell Temperature is computed from the following heat balance [18-23];

$$mC_{p\_module}\frac{dT_C}{dt} = Q_{in} - Q_{conv} - Q_{elect} \quad (3)$$

Where;

TC: Pv Cell Temperature

mCp_module: Thermal capacity of the PV module

t: time

Qin: Energy received due to solar irradiation

Qconv: Energy loss due to Convection

Qelect: Electrical power generated

And the Solar energy absorbed by the PV cell, Qin, is given by equation (3).

C. Thermal energy incident in a PV cell

The electrical power generated is given by;

$$Q_{elect} = \eta G S_c \quad (4)$$

η: Module efficiency

Sc: Total surface area of PV cells in a module

The thermal energy transferred from the PV cells 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 [1,17 through 23];

To close the energy balance in the equation (4), the heat transfer by convection and by radiation are determined respectively using the convection heat transfer coefficient and emissivity PV cell Stefan-Boltzmann constant. Interested readers in the calculation of the heat balance in the equation (7) are advised to consult Sami [23,30].

The finite-difference formulation was used to determine

the heat transfer fluid temperature as follows at each element using the following equation. The heat transfer fluid tube is divided into, nTE, elements;

$$T_f = T_{f\_in} + \frac{\partial Q}{m_{water} C_p} \times t \quad (5)$$

t: time

Tf_in: Fluid temperature at the inlet and represents the time step iteration

The thermal energy transferred from the PV cell to the heat transfer fluid is obtained by;

$$Q_{Thermal} = \dot{m} \times C_{p\_water} \times \Delta T(T_{fHx+1} - T_{f\_In}) \quad (6)$$

QThermal: Energy from the thermal process

TfHx+1: Fluid temperature at thermal element 1

The energy transferred to heat transfer fluid is calculated by the integration of the aforementioned equations along the length of each tube. In this analysis, the mainstream temperature of the heat transfer fluid flow was considered as the average temperature of the inlet and outlet of each finite-difference element;

$$Q_{in} = \dot{m}w\, C_{p\_water}(T_{f+1} - T_f) \quad (7)$$

ṁw : Water flow.

Tf+1: Water temperature at the next element.

Cp: Specific heat of HTF.

Finally, the hybrid system PV-thermal energy conversion efficiency for harnessing energy from solar radiation is given;

$$\eta_{SH} = \frac{P(t)+Qthermal}{Qin} \quad (8)$$

Where Qthand Qin is the solar thermal heat transferred to the HTF and solar irradiance, the respective values are given by equations (1) and (8), respectively. Besides, $P(t)$ Is the PV solar electrical output and defined by equation (2).

D. Nanofluid heat transfer Fluid

The basic heat transfer fluid in the PV-Thermal loop, as shown in Figure.1, is water-based nanofluids. Nanofluids have been added to the water-based flow to enhance their thermal properties. References [14-34] presented equations to calculate the thermophysical and thermodynamic properties of nanofluids such as specific heat, thermal conductivity, viscosity, and density employing the law of mixtures, as a function of the volumetric concentration of nanoparticles;

$$\alpha \text{ total} = \alpha \text{ particles} + \alpha \text{ base fluid} \quad (9)$$

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

The nanofluid thermal and thermophysical properties, αtotal, can be calculated as follows;

$$\alpha \text{ total} = \alpha \text{ base fluid} + \alpha\text{particles}.(\Phi) \quad (10)$$

Where; Φ represents the nanoparticles' volumetric concentration.

E. Thermophysical Properties with Magnetic Field

The field-dependent thermal conductivity of magnetorheological fluids plays an important role in heat transfer and dissipation in potential new applications. Magnetic nanofluids with a low concentration of nanoparticles can significantly enhance their thermal. This research considers that magnetic metallic solids under different magnetic forces Gauss improve thermal and thermophysical properties compared to those of fluids, and nanofluids and exhibit significantly higher thermal properties compared to conventional heat transfer fluids. In the following, we present the formulas developed based upon the magnetic data published in the literature properties [10 through 31]; was used to taking into account the impact of the magnetic field as outlined in Table.1

Table.1: Thermophysical properties as a function of magnetic field forces in Gauss[30]

	Ai203	CuO	Fe304	SiO2
Cp nf	b = 0.1042a + 6226.5	b = 0.2011a + 5730.8	b = 0.8318a + 4269.8	b = 0.6187a + 4293.2
K nf	b = 2E-05a + 1.4888	b = 5E-05a + 1.3703	b = 0.0002a + 1.0209	b = 0.0001a + 1.0265
h	b = 0.0031a + 73.092	b = 0.0031a + 73.073	b = 0.003a + 73.225	b = 0.003a + 73.231

Where “b” represents the nanofluid specific property, and “a” is the magnetic field force in Gauss. Cpnf, Knf, and h are the specific heat, thermal conductivity, and heat transfer coefficients of nanofluids.

Equation (10) can be used to determine other thermophysical properties such as; α is the thermal diffusivity, ʎ and ρ represent the thermal conductivity and density as a function of the properties outlined in the Table.1

F. Heat Pipe Model

For the heat pipe to work properly, the pressure drop in the fluid flow embedded in the heat pipe has to be compensated by the pumping pressure in the wick and the capillarity as prescribed by Sami [16, 31], Tardy, and Sami [33], Endalew [19], and Reay and Kew [32];

$$\Delta P_p = \Delta P_i + \Delta P_v + \Delta P_g \quad (11)$$

Where ΔPp, ΔPl, ΔPv, and ΔPg are the total pumping pressure, pressure drop for liquid return from the condenser, pressure drop for vapor flow in the evaporator, and gravity head, respectively.

The heat transfer limit for a heat pipe depends on the construction of the heat pipe and the operating environment. the design of the heat pipe and the wick properties are determined by the thermophysical properties of the working fluid used [30,32].“The heat pipe heat transfer capillary, sonic, entrainment, boiling, frozen start-up, continuum vapor, vapor pressure, and condenser effects determine the physical phenomena that establish the lowest limit of these phenomena and are considered as a design limit”.[30,32]

The energy conversion and efficiency of heat transfer from the evaporator section of the heat pipe to the condenser section in the solar application becomes one of the important selection criteria for the working fluid. Hence, the use of working fluid with higher latent heat is very beneficial to the applications of the heat pipes in solar energy conversion. Water and different refrigerants such as R-134a, R-123, R-32, R-125, R-152a, R-1234ze, and R-1234fz, as well as refrigerant mixtures Sami [30,38], are considered in this investigation as working fluids inside heat pipe.

The energy balance under natural convection heat transfer condition in the thermal storage tank as per Figure .1, using a single-control volume of heat pipe submerged in the thermal tank is presented in the following equation), [13, 16, 30];

$$V_w P_w C_w \frac{dT_w}{dt} = \pi do I_{cond} h_{eff}\left(T_{hp} - T_w\right) - U_{\tan} A_{tan}\left(T_{hp} - T_a\right) \quad (12)$$

Where Vw represents the water volume in the thermal tank and Utan and Atan are the overall heat transfer coefficient in the thermal tank and the equivalent heat transfer area in the tank, respectively. Besides, Thp, Tw, Ta are the temperatures of the heat pipe, water, and ambient air.

To determine the heat capacity of the condenser section of the heat pipes, the following energy and mass balance equations are considered;

$$Q_{cond_{hp}} = H_{eff} * \left(T_{hp} - T_w\right) * d_o * I_o * \pi \quad (13)$$

Where Io is the length of the condenser section of the heat pipe.

On the other hand, the thermal energy dissipated into the thermal tank from the heat pipes and delivered for the domestic or industrial end-user is;

$$Q_{tt} = \eta_{hx} * m_{w_{Qtt}} * C_{p_w} * (T_{12} - T_{13}) \quad (14)$$

Where the $m_{w_{Qtt}}$ Represents the water mass flow rate circulating between the thermal tank and the user application in question. T12 and T13 are the supply and return temperatures from the end-user application, respectively. ηhx is the thermal tank efficiency.

The efficiency of the solar PV panels can be expressed as follows;

$$\eta_{pv} = \frac{Q_{elec}}{Q_{collector}} \quad (15)$$

Where Qelec is calculated by equation (1) and Qcollector is obtained by equation (2).

The thermal efficiency of the heat pipe can be obtained by the following equation;

$$\eta_{hp} = \frac{Q_{cond_{hp}}}{Q_{cond_{hp}}} \quad (16)$$

Where, $Q_{cond_{hp}}$represents the heat released by the condenser section of the heat pipe

Finally, the hybrid system energy conversion efficiency for harnessing energy from solar energy using the thermal panels and heat pipe can be formulated as;

$$\eta_{sh} = \frac{Q_{evap_{hp}} + Q_{elec}}{Q_{collector}} \quad (17)$$

Where Qelec is calculated by equation (1)

III. Numerical Procedure

The energy conversion equations and heat transfer mechanisms of nanofluids under the magnetic field force taking place during various processes PV-Thermal shown in Figures.1 and were outlined in the model presented in Equations (1) through (17).

The aforementioned energy conversion equations have been solved as per the logical flow diagram presented in Figure 2, where, the input parameters of the solar PV conditions such as solar radiation, ambient temperature, and humidity as well as other independent parameters such as nanofluids and magnetic filed force are defined. The dependent parameters were calculated and integrated into the system of finite-difference formulations developed after the energy conservation equations under nanofluids and magnetic fields. Iterations were performed until a converged solution was reached with an acceptable iteration error.

The numerical procedure as per Figure .2 started by using the solar radiation, ambient conditions to calculate the solar

PV cell temperature, and PV cell back the temperature as well as the heat transfer fluid mass flow rate circulating in the thermal closed-loop using nanofluids and under magnetic field at specified conditions. The thermodynamic and thermophysical properties of Heat Transfer Fluid were employed to calculate the water-based nanofluids flow rate. This was followed by using the finite-difference formulations to predict the time variation characteristics of the PV cell temperature, the PV back temperature, and thermal heat transferred to the Heat Transfer Fluid, Heat transfer fluid outlet temperature at the heat exchanger, as well as other hybrid system power outputs and efficiencies. Finally, hybrid system efficiency was calculated at each input condition of nanofluids, concentrations, and magnetic field force.

IV. Results and Discussion

Equations (1) through (17) representing the present numerical model have been solved, taking into account the heat and mass transfer mechanisms during the solar PV-Thermal energy conversion process under different solar radiations, magnetic field forces, and nanofluids. The above-mentioned equations were coded with finite-difference formulations and solved as per the logical flow chart depicted in Figure.2. Besides, the predicted simulated results for PV-Thermal solar panels were compared to the data published in the literature under various conditions.

In the following sections, we present analysis and discussions of the numerical results predicted as well as validations of the proposed simulation model. The simulations were performed at different temperature differences across the thermal tubes of the heat exchanger welded beneath the PV solar panels; however, only results will be presented and analyzed for the temperature difference of 15 °C across the thermal tube. It is worthwhile noting that the numerical simulation presented hereby was conducted under different conditions such as; PV cell temperatures from 10°C through 38°C, ambient temperatures from 10°C through 38°C, solar radiations; 500, 750, 1000, and 1200 w/m2, different nanofluids; A2O3, FE304, SiO2, CuO at various concentrations; 5,10 and 20% and under a magnetic force that varied from 127 Gauss up to 3000 Guass.

The PV panel characteristics under consideration in this study were obtained from Fargali et al. [34]. The parameters adopted in this study were; 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), the overall absorption coefficient is 0.73, and Temperature coefficient is 0.0045 K-1. Interested readers in the full range values of the other parameters are advised to consult Fargali et al. [34] and Sami [30].

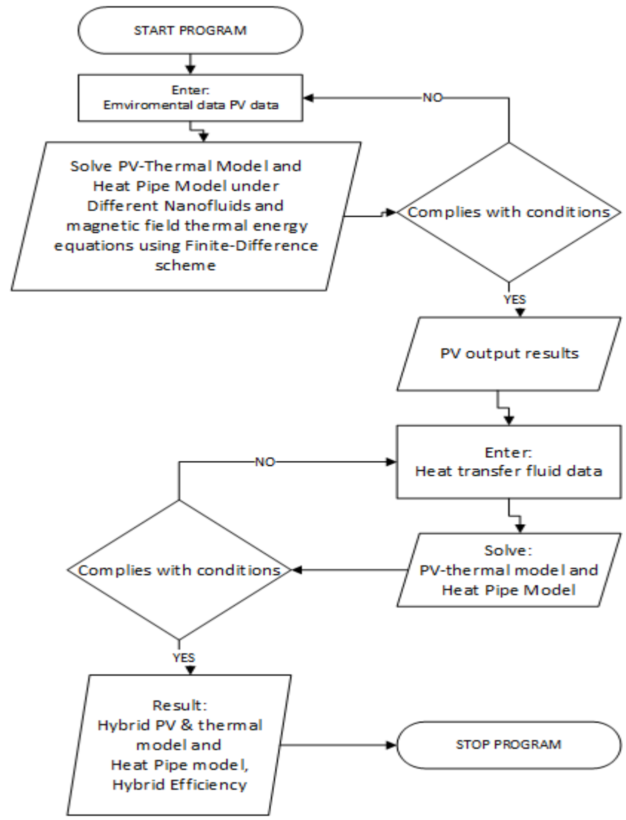

Figure.2 Logical flow diagram

It was also assumed in this simulation that the whole panel was covered in PV cells, with no packing material (the material used to fill in gaps between the cells on a panel. The PV cells are commercial grade monocrystalline silicon cells with an electrical efficiency of 12% and have a thermal coefficient, of 0.54% [1/K] Sami [30].

As per the equations outlined above, and results presented in Figure .3, the increase in the PV cell temperature due to solar radiation resulted in an increase in the back cell temperature and consequently the heat transport water-based fluid temperature due to the heat transfer from solar energy by conduction and convection as well as radiation, respectively. It has been demonstrated by Sami [30] that the higher the cell temperature, the higher the back cell and heat transport water-based fluid temperatures, and the higher the solar radiations, the higher the energy absorbed by the PV cell, and consequently the higher the temperature of the cell until reaches the design temperature. For further details, interested readers are advised to consult Sami [30]

The effects of the PV panel operating temperature on the output efficiency have been well documented in the literature [14 through 30], where the increasing temperature of the PV cell decreased the amount of power available. However, it is important to note that the changes in the PV cell temperature caused by solar radiation have a dynamic nature. The PV panel heats up and cools down gradually depending upon the changes in solar radiation in dynamic response and consequently the power output from the PV panel. It was quite evident from the results reported in the literature, namely Sami [30] and others presented in Figure .3, that the cell temperatures, as well as the other ones, increase with the increase of solar radiation. This can be interpreted as per equations (1) through (3), where the dynamic cell temperatures are expressed in terms of the heat balance across the PV cells.

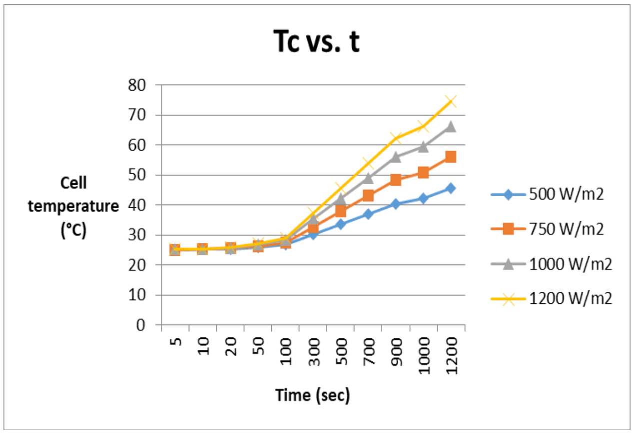

Figure.3 Cell temperatures at different solar radiations

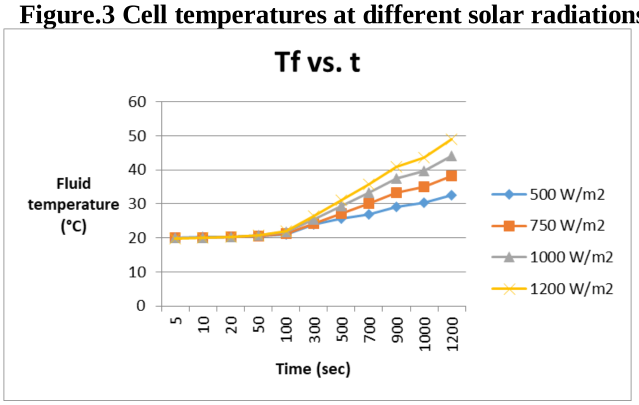

Figure.4 Heat transport fluid temperature at different solar radiations.

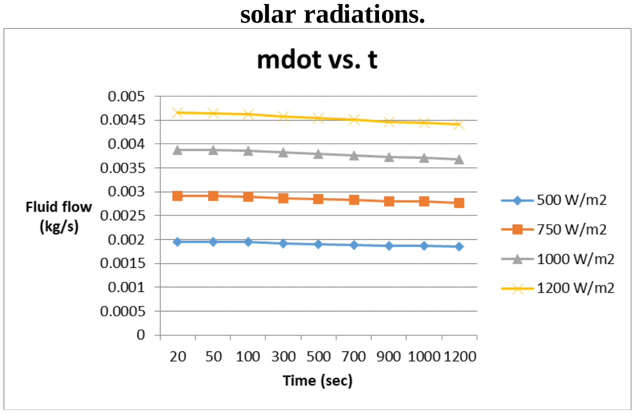

Figure.5 Water mass flow rate at different solar radiations and heat exchanger temperature difference 15 °C.

The results presented in Figures.4 and 5showed that the higher the solar radiation, the higher the thermal energy absorbed, and the longer the time, the slightly the mass flow rate of the heat transport water-based fluid is reduced. The results also showed, as expected the heat transport fluid mass flow rate increased at higher solar radiation as well as the heat transport fluid temperatures. This is because the higher solar radiation resulted in higher thermal energy transferred to the fluid flow, and consequently, this increased the heat transport temperatures and the fluid flow mass flow rate.

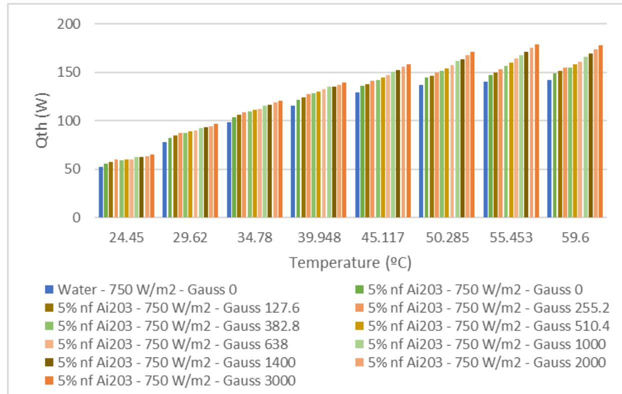

Figure.6 Thermal energy generated at PV-Th solar panels

Nanofluid Ai2O3 has been reported the most and studies in the literature for comparison purposes. Figures .6and 7 were constructed to analyze the different parameters of the thermal energy converted and transferred to the nanofluid Ai2O3 heat transport fluid at different temperatures and concentrations %5, circulating beneath the PV-Th solar panel under solar radiation of 750 w/m2 and at different magnetic fields forces. Also, as it can be observed, the higher the magnetic field, the higher the thermal energy dissipated from the heat pipe at the condenser side into the storage tank.

The heat pipe condenser section's thermal energy calculated by equation (13) has been plotted in Figure .7 at different heat pipe temperatures. This thermal energy was transferred from the evaporator section of the heat pipes through the heat pipe filled in working fluid and appeared to show that its dependence upon the magnetic field; however, the higher the heat pipe temperature, the higher the heat pipe condenser section's heat dissipated into the thermal storage tank. As discussed in Sami [30], the thermal energy transferred to the nanofluid heat transfer fluid increased the heat transport fluid flow rate and the heat pipe temperature; thus, it can be concluded that the magnetic field indirectly impacted the thermal heat developed at the heat pipe condenser section.

The hybrid thermal efficiency of the proposed system, as defined in equation (17), was determined as thermal energy and electrical power generated divided by the solar radiation absorbed by the PV solar panel. Also, the heat pipe efficiency has been calculated by equation (16), It is quite evident from the results presented in Figures.8, and 9 that the higher the magnetic field, the higher the hybrid thermal conversion efficiency and the higher the heat pipe efficiency.

The results in these figures also demonstrated that the higher the magnetic field, the higher the nanofluid heat transport temperatures, and the higher thermal energy transferred to the heat transport nanofluid. Further, Figures8 and 9 confirm that the higher the magnetic field, the higher the heat dissipated from the heat pipe condenser and the higher the heat pipe efficiency.

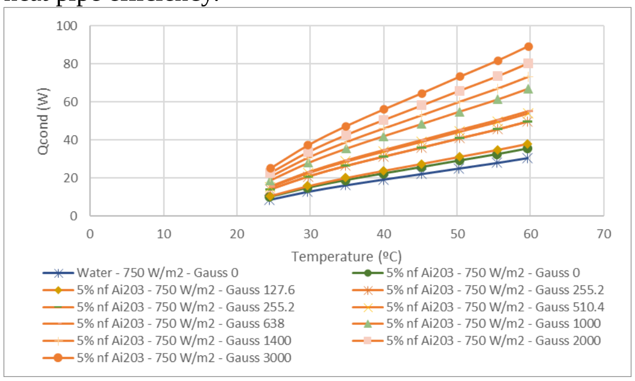

Figure.7 Thermal energy at heat pipe condenser generated by PV-Th solar panels

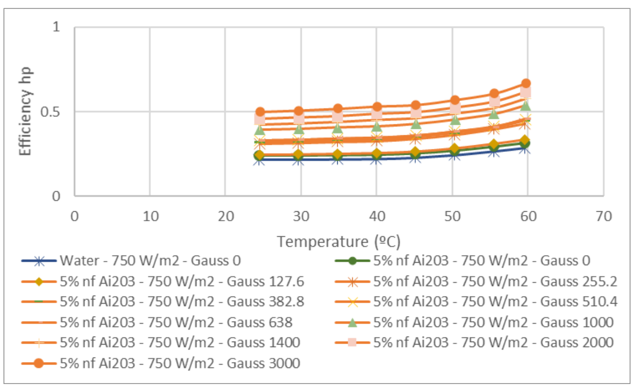

Figure.8 Thermal efficiency of heat pipe evaporator generated by PV-Th solar panels

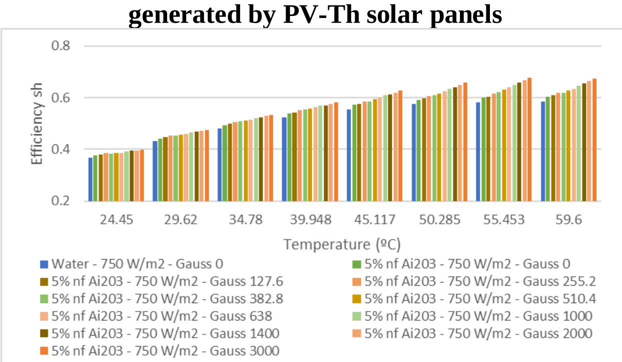

Figure.9 Thermal efficiency of hybrid system generated by PV-Th solar panels

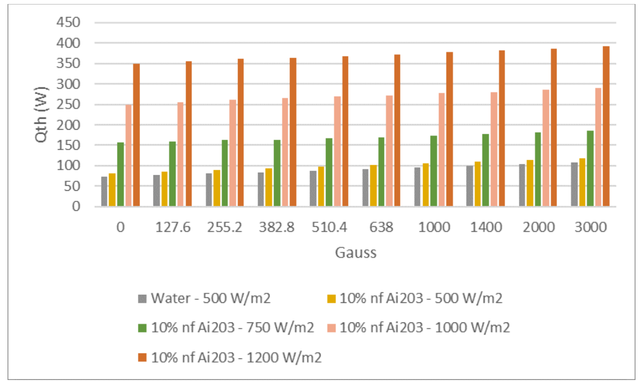

Figure.10 Thermal energy of hybrid system generated by PV-Th solar panels

The effect of solar radiations on the PV-Th integrated heat pipe loop was demonstrated in Figures 10 through 13, for nanofluid Ai2O3 at a specific concentration where the key parameters of the PV-Th hybridimpacting the heat pipe behavior such as thermal energy transferred from PV-Th solar panels, the efficiency of the hybrid system, and heat pipe efficiency were displayed at solar radiations of 500, 750, 1000 and 1200 W/m2. The results in the aforementioned figures showed that the higher the solar radiation, the higher the thermal energy transferred to the nanofluid loop feeding the heat pipe evaporator section. In turn, this thermal energy was enhanced at higher solar radiation that results in the enhancement of the heat developed at the heat pipe condenser section and consequently increased the heat pipe efficiency

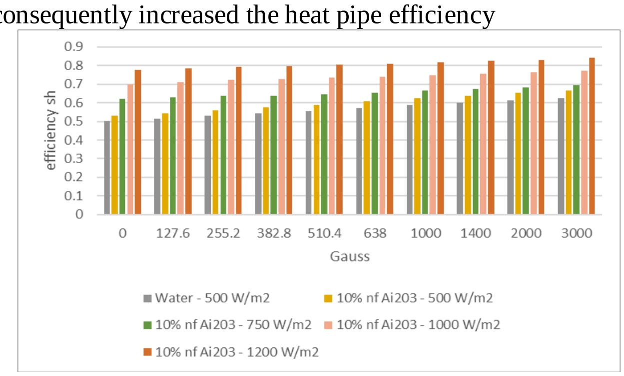

Figure.11 Thermal efficiency of hybrid system generated by PV-Th solar panels

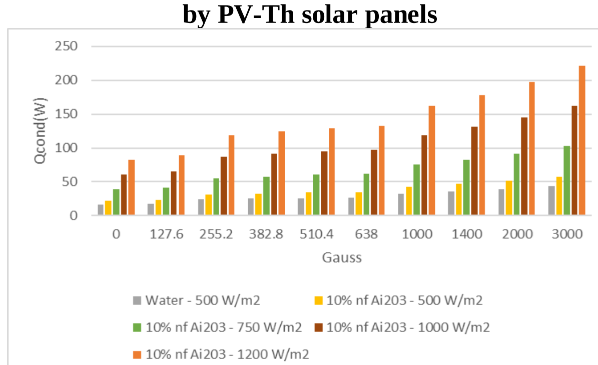

Figure.12 Thermal energy developed at heat pipe condenser generated by PV-Th solar panels

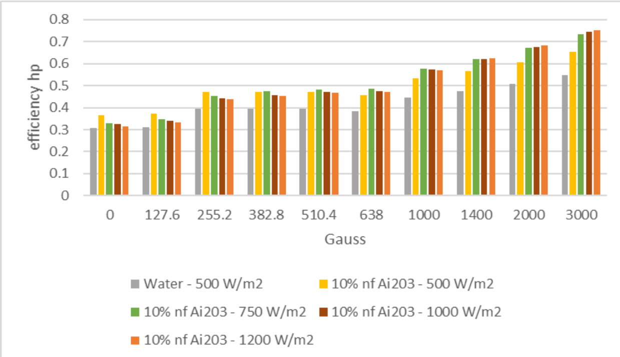

Figure.13 Thermal efficiency of heat pipe generated by PV-Th solar panels

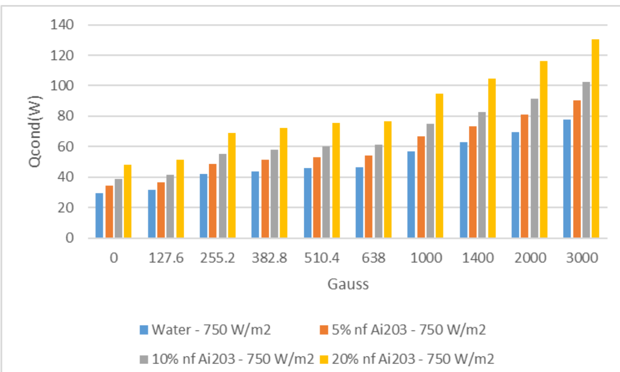

Figure.14 Thermal energy at the condenser of heat pipe generated by PV-Th solar panels

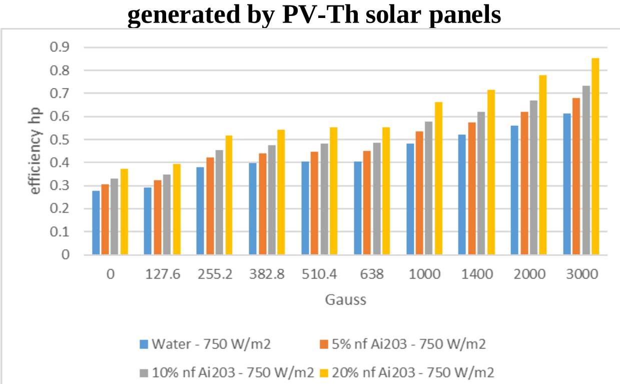

Figure.15 Thermal efficiency of heat pipe generated by PV-Th solar panels

As reported in References [1-14-,30, 34], the thermophysical and thermodynamic properties of nanofluids such as specific heat, thermal conductivity, viscosity, and density employing the law of mixtures, as a function of the volumetric concentration of nanoparticles; equations (9) and (10) significantly influence the characteristics of nanofluids at the different magnetic fields and in particular the behavior of heat pipes. In particular, Figures 14 and 15 have been constructed to illustrate that the higher the nanofluid concentrations, the higher the thermal performance. This was due to higher concentrations of nanofluid enhanced the thermophysical properties of the heat transport fluid, heat transfer coefficient, and the thermal energy transferred. As seen in these figures, higher thermal energy dissipated at the heat condenser side, and the efficiency of the heat pipe occur at higher nanofluid concentration; however, higher concentrations induce higher fluid friction and pressure drop in the hybrid system that have negative effects on the system performance and its hybrid efficiency. . Similar observations were noted regarding the other main key parameters of the heat pipe and hybrid system in questions at the different nanofluids. Therefore, it is paramount for the designer to strike a balance between heat pipe performance and the chosen nanofluid concentration to achieve the best and optimize the hybrid system performance

It is also believed that the enhancement of characteristics of the nanofluids was caused by the increase in thermal conductivity of the magnetic nanofluids and can be explained by the interaction among the dispersed nanoparticles and how their behavior changes in the presence of a magnetic field. The phenomenon of enhancement of thermal conductivity can be explained based on chain formation due to particle-particle interactions and alignment along the magnetic field [18 through 27] and Sami [30]), which resulted in the formation, conducting, and diffusing of thermal energy.

Another angle of this study is to study the impact of using different nanofluids. During this investigation, we observed that the nanofluid concentrations have a significant effect on the system's main characteristics, such as the thermal energy transferred to the nanofluid heat transport fluid, thermal energy released by the heat pipe condenser, heat-pipe efficiency, and the hybrid system thermal efficiency. The results displayed in these figures demonstrated that the CuO exhibits superior characteristics over the other nanofluids presented in figures; 16 through 18, Ai2O3, Fe304, and SiO2; thus, the use of nanofluidCuO resulted in higher performance of the above-mentioned parameters compared to the other heat transport fluids including the water base. Because the nanofluidCuO has higher thermodynamic and thermophysical properties higher than the other nanofluids under investigation, including the water as heat transport fluid. It was also observed that the higher the nanofluid concentrations, the higher the thermal performance and, in particular, the heat pipe efficiency. Also, Figures 16 through 19indicated that the higher the Gauss magnetic intensity, the higher the thermal performance of the hybrid system and thermal energy released by the condenser section of the heat pipe.

As reported by reference [27-30, 36], the increase in thermal conductivity under an external magnetic field is attributed to the effective conduction of heat through the chainlike structures[47] through [50]. Figure .19 gave a piece of clear evidence that the heat pipe thermal efficiency has been enhanced at higher CuO concentrations compared to the water-based heat transport fluid, which was caused by the increase of thermal conductivity of the heat transport fluid as discussed earlier in the paper. Readers interested in this subject matter are advised to consult these references [27-30, 36, 47-50}.

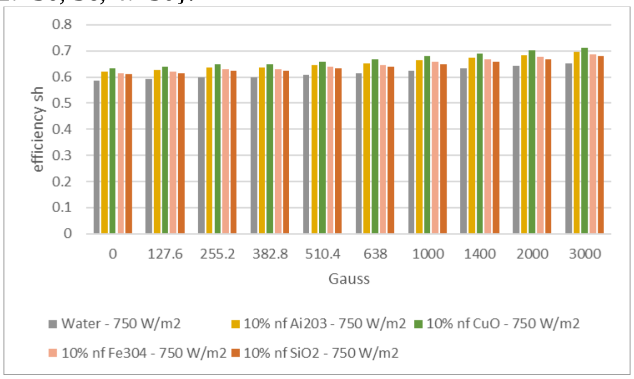

Figure.16 Thermal efficiency of hybrid system generated by PV-Th solar panels with different nanofluids

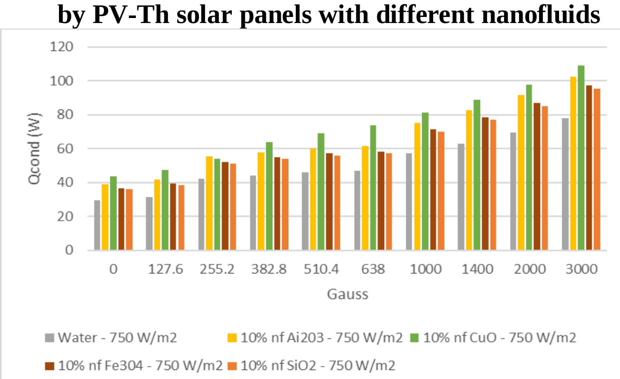

Figure.17 Thermal energy released by heat pipe condenser generated by PV-Th solar panels with different nanofluids

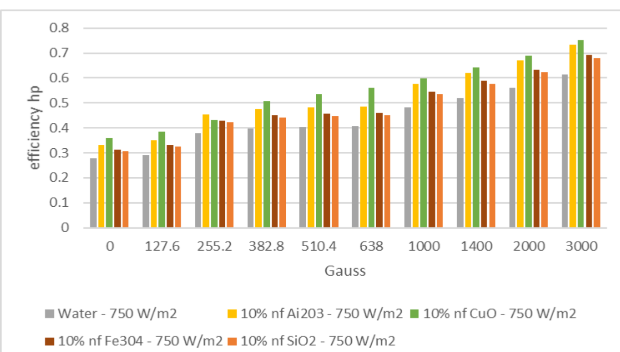

Figure.18 Thermal efficiency of heat pipe generated by PV-Th solar panels with different nanofluids

V. Model validation

The numerical results predicted by the model described above have been validated with data presented in the literature for solar PV, namely references [34,30, 56]. In particular, it is quite apparent from the comparison presented in Figure. 20that the model prediction fairly compares with the data of the dynamic PV cell temperature presented by Fargali et al. data [34], also showed that the model and data have the same trend; however, some discrepancies exist. The discrepancies are becauseFargali et al. [34, 56] did not provide full disclosure of the various parameters used.

The thermal energy was calculated under a magnetic field has been compared to experimental data on the magnetic field, and nanofluids were scared and hardly reported in the literature. The data reported by references[49-51] on nanofluid Fe304 were considered and compared at the different magnetic fields up to 7000 Gauss and at a temperature difference of 15 C. The nanofluid Fe304, the choice for his study, was found to be the nanofluid with a 0.1% volume concentration. The results of our model prediction were compared to the data of references [49-51] at similar conditions and plotted in Figure. 20. The comparison showed discrepancy exited and varied between 8% to 14% with the model over predicting the experimental data.

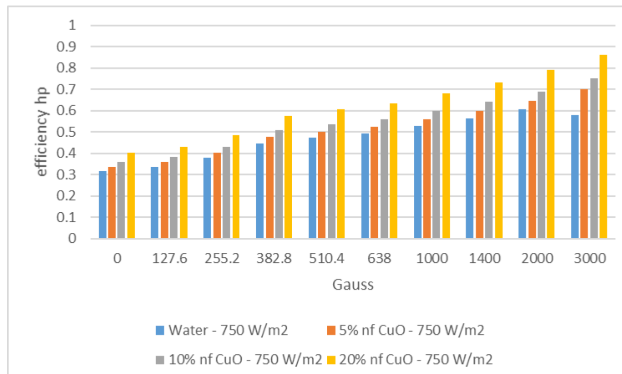

Figure.19 Thermal efficiency of heat pipe generated by PV-Th solar panels with different nanofluids

VI. Conclusions

The energy conversion equations describing the mass and energy balances of a novel combined concept of a photovoltaic-thermal solar panel integrated heat pipe hybrid system has been developed, integrated, and solved to predict the total dynamic power generated, efficiencies of the hybrid system and heat pipe, and the important key parameters under different solar irradiance, using nanofluids; Ai2O3, Cuo, Fe304, SiO2, and Cuoand different magnetic field forces. The model was based on dynamic mass and energy equations coupled with the heat transfer coefficients, thermophysical properties of magnetized nanofluids, thermodynamic constants, and as well as other material properties.

It is evident from the results presented in this paper that the higher the solar radiations, the higher the thermal and the higher the hybrid system efficiencies and also the higher the heat pipe efficiency and heat released by the condenser. Furthermore, the PV simulation study results showed that the higher the solar radiation, the accelerated increase in the PV cell temperature. Consequently, it also shows the higher the solar radiation, the higher the PV cell temperatures, power, and PV amperage. As far as the simulation of PV-Th, it was demonstrated that the higher the nanofluids concentration, the higher the hybrid system characteristics and the higher the heat released at the heat pipe condenser section and efficiency. Besides, the higher, the magnetic field, the higher the thermal energy and the hybrid system efficiency and heat pipe efficiency. Finally, it was shown that the nanofluidCuOexhibited the highest hybrid system characteristics and heat pipe performance compared to the other nanofluids including water-based fluid.,under consideration.

The designer of the PV-Th solar panel integrated heat pipe hybrid system must take into consideration the solar radiation, type of nanofluid as well as ambient conditions. Finally, the model prediction was compared fairly with the PV-Thermal data available in the literature on magnetized nanofluids at different conditions of solar radiations, nanofluid concentrations, and magnetic field forces.

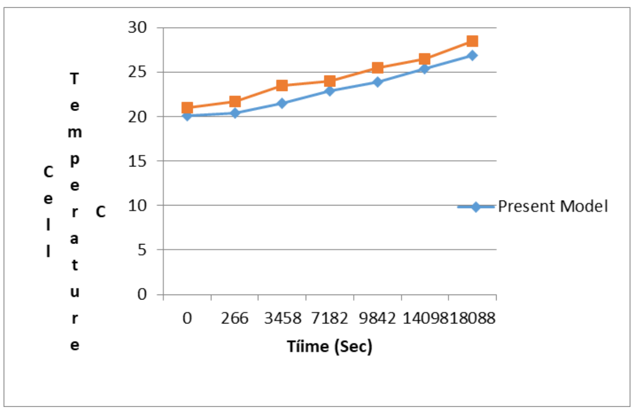

Figure 20. Comparison between present model prediction for cell temperature and Fargali et al. data [34].

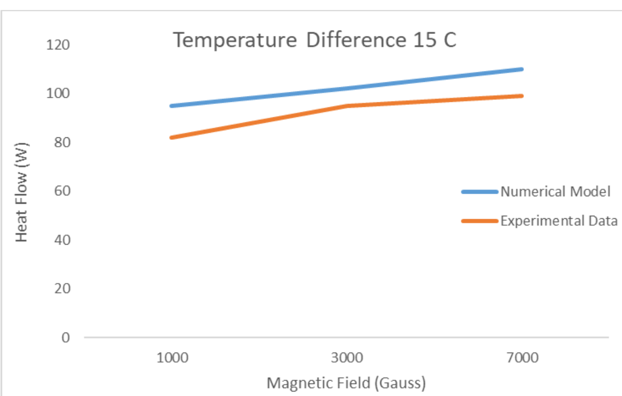

Figure 21. Comparison between present model and data for Nanofluid Fe 304 data at different magnetic fields [49].

VII. Nomenclature

C_{p_water} Thermal capacity of water (J/kgK)
D Internal Pipe diameter (m)
G Total Solar radiation incident on the Pv module (W/m^2)
H Convective heat transfer coefficient module (W/m^{2}K)
h_{water} Heat transfer coefficient (W/m^{2}K)
IOutput current of the Pv module (A)
$\dot{m}$ Water flow (Kg/s)
mC_{p_module}Thermal capacity of the Pv module
m_{water} mass of water (Kg)
N_{pipes} Number of pipes
N_s Total number of cells connected in series
nTE number of Thermal Elements in a pipe
P Power generated by Pv module (W)
Pa Atmospheric pressure of moist air (Pa)
pw Partial pressure of water vapor in moist air (Pa)
$Q_{conduction}$Energy due to conduction (W in Electrical Process) (W/m^2 in Thermal Process)
$Q_{convection}$Energy due to convection (W in Electrical Process) (W/m^2 in Thermal Process)
Q_{elect} Electrical power generated (W)
Q_{in} Energy received due to Solar irradiation (W/m^2)
Q_{in_cell} Energy incident on one Pv cell due to solar radiation (W/m^2)
$Q_{radiation}$ Energy due to radiation (W/m^2 in Thermal Process)
$Q_{Thermal}$ Energy from thermal process (W)
S_c Total surface area of Pv cells in a module (m^2)
S_p Total area of the PV module (m^2)
T Operating temperature (k)
T Time (s)
T_a Ambient temperature (°C)
T_C Pv Cell Temperature (°C)
T_{db} Dry bulb temperature (°C)
T_f Fluid temperature (°C)
T_f Fluid temperature (°C)
T_{f_in} Fluid temperature at the inlet (°C)
T_{fHx}Maximum temperature at the Heat Exchanger (°C)
T_{fHx+1}Fluid temperature at thermal element 1 (dx) (°C)
T_m Module Back-surface temperature (°C)
T_r Nominal temperature (298.15 K)
U Thermal conductance of clean heat exchanger (W/m2K)
UdThermal conductance of heat exchanger after fouling (W/m2K)
V Output voltage (V)
α_{abs} Overall absorption coefficient
η_{Hybrid} Hybrid system efficiency
ηPvPV module efficiency
$\eta_{Thermal}$ Efficiency of thermal process
ρwDensity of water vapor (Kg/m^3)
∂Q Convection heat transfer rate
ε Emissivity PV cell

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