كلية الهندسة بشبرا
FACULTY OF ENGINEERING AT SHOUBRA
ERJ
PRINT ISSN 3009-6049
ONLINE ISSN 3009-6022

ENGINEERING RESEARCH JOURNAL (ERJ)
Volume (52) Issue (4)
October 2023, pp:9-15
https://erjsh.journals.ekb.eg

An Implemented Structure for enhancing the Electrical Output Power of a Photovoltaic Module Based on Active Nano-fluid cooling Technique

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Abstract: Photovoltaic panels (PV) are considered one of the solutions to face climate change and pollution. A PV/Thermal system is used as a result to raise the output power of the PV modules by decreasing their temperatures. This work includes numerical and experimental outputs, a comparison between the electro-thermal behaviours of water and different percentages of AL_2O_3 Nano-water (0.001 & 0.01) pass through a new back pipe structure (pancake) installed under the PV module is presented. Comsol Multiphysics and MATLAB simulators are utilized to apply the model. The experimental work runs for both Nanoparticle concentrations compared with water. The pumping power consumption is approximately 1% from the average output power of the system. The thermal results for 0.01 %wt of AL2O3 Nano-water show that the PV module temperature decreased about 14.04 % and 8.8 % compared with water and 0.001 %wt Alumina, respectively. In addition, the difference in water temperature is increased by about 21.6 % and 6.7 % for two different concentrations compared with water. That leads to enhancement in the module's daily output power up to 14.6 % by using 0.01 wt% AL2O3 Nano fluid compared with cooling water.

Keywords: Photovoltaic/Thermal (PV/T) Hybrid System; cooling systems; MATLAB; Solid works.

1. INTRODUCTION

Photovoltaic (PV) is a major renewable source of energy, which replaces fossil fuels because of its profusion [1]. The Middle East and North Africa (MENA) region has a large amount of solar irradiance located on its territory. These countries in this region prefer the wind more than the PV modules due to the rise in weather temperature and lots of desert areas. As a result, various cooling methods can increase the electrical output of PV panels. [2], are considered as the main source for increasing the temperature of the PV modules. This unexploited heat affects the performance of the PV panels negatively as indicated in the literature [3]. Accordingly, many investigations have been conducted to limit such effects and maintain the module's temperature at its nominal value.

Previous Works have revealed that the PV module temperature is increased by the absorbed portion of energy from the sun which is not transferred to electrical power, thus reducing its overall efficiency [4]. For polycrystalline silicon solar cells (pc-Si), the relation between the productivity of the PV module is inversely proportional to the module's current working temperature, whereas it decreases 0.34% for every degree Celsius increase [5]. This relation however is only applicable above 25 ºC, where it reaches 60 ºC in the MENA region [6].

In order to decrease high module temperature, several passive techniques [7] which have been proved in previous works, are presented. In the case of an active cooling technique, the cooling fluid is the major factor, which impacts the system performance [3]. Air [8, 9], water [10, 11], and nano-fluids [12, 13] have been listed as cooling fluids to reduce PV module temperature.

Talib K. [14] introduced a titanium dioxide nanofluid cooling liquid for three photovoltaic panels with different concentrations (1 wt%, 2 wt%, and 3 wt%) the ultimate efficiency was (19.23%) achieved by the (3 wt%)

concentration. of nanofluid. Husam Murtadha [15] Provided a concentrated frencel –based PV modules utilizing water/Al_2O_3 Nanofluid, and water for cooling, the ultimate heat transfer achieved by water/Al_2O_3 Nanofluid was 23% compared with water, and this resulted in electrical efficiency enhancement.

El-Mahallawi [16] Introduced the PV system has integrated coating materials in the manufacturing of the PV glass like paraffine which is Monolithic hydrophobic and by addition of nanoparticles TiO_2 raise the electrical efficiency of the PV module from 14% to 17%. A. Kazem [17] presented a PV/T system by using nano-silicon carbide (SiC) and paraffin as a cooling medium through serpentine copper pipes, which improved the electrical efficiency 13.7%.

The weakness in the previous study the air increase the efficiency of the output power with 2.1% [8], with water the increase in the efficiency is about 6.7%[11],but the increase in the efficiency by using nano fluids depends on the type of nano particles mixed with water like Ci2o3 [4] in This work presents a comparison between water and two different concentrations of AL2O3 nano-water (0.01 % and 0.01%). The cooling fluid entered through pancake form of pipes, the simulation and experimental works meant the ability to increase the electrical power from the system, and the result of the various cooling fluids will demonstrate the best cooling fluid performance.

2. PV/T SYSTEM MODEL DESCRIPTION.

A fixed PV/T system consists of the same three poly-crystalline PV panels introduced in Figure 1. The engineering drawing is done by solid works [18] and then transfer to Comsol Multiphysics commercial platform [19]. The model is designed under conditions as follows: a closed loop and laminar flow through the cooling pipes. Under supplied heat transfer equations in the simulator program, the model is used to study the PV module temperature and fluid convective heat inside the pipes. Via the results data obtained from the simulation, the electrical properties of each structure are obtained using the MAT-Lab program [20]. Each PV panel in the system has a pancake shape attached to the backside with the same length.

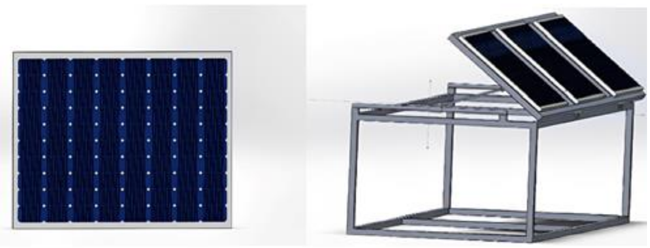

Fig 1: The PV module, and a test rig produced by Solid-works [18].

The system has dimensions of 2010 L X 1920 W X 1670 H mm. Each PV panel has the same dimensions of 670 L X 540 W X 25 H mm and the maximum output power of about 50 watts (I_{max} =2.8618 A, and V_{max} =18 Volts, I_{SC} = 3.17 A, V_{SC} = 21.6 Volts, $T_{\text{operating cell Temperature}}$ = 25 °C). The system is fixed at a 30-degree inclination angle towards the south to the equator to receive the maximum irradiance all over the year in Egypt [21, 22].

Figure 2 shows the proposed (pancake) shape which has a length of 6.18 m and dimensions of 0.011 m and 0.012 m for inner and outer diameters, respectively. This shape is made of copper material and fabricated with a circular entrance. The inlet flow has the same average velocity of 0.04 m/s to reach approximately an almost equal pressure drop and flow distribution [11]. The reasoning behind choosing copper as the pipe material is its higher thermal conductivity and ease of use due to being well-researched [17].

Fig 2: An engineering drawing for pancake shape [19].

3. THEORETICAL WORK.

In order to prove the laminar fluid inside the pipes, the Reynolds number is calculated to be 1250 for a new shape. Therefore, the flow rate through the pipe is chosen to be 1.2 L/min [23] to decrease the PV module temperature and increase the electrical output power of the system. The Reynolds number was enumeration for a pancake shape by Eqn. (1) as follows [23]:

$$R_e = \frac{v_{avg} D}{u} \tag{1}$$

The pressure drop is calculated using the Darcy–Weisbach equations [24] and found to be 259.2 Pa. using Eqn. (2):

$$\frac{DP}{L} = f_D \frac{D}{2} \frac{(v_{avg})^2}{D} \tag{2}$$

After the solar panel emits the heat energy from the Sun irradiance it transfers that solar radiation to the pancake pipes. Thus, the fluid can absorb the energy from copper pipes. The emitted heat loss from the Sun irradiance can be solved by Eqn. (3) [24].

$$Q_{emmited} = e.s.(T_{PV}{}^4 - T_{amb}{}^4) \tag{3}$$

The convective heat transfer coefficient of the front and back side of the PV/T system was calculated by Eqn. (4) for all cases as follow [23]:

$$Q\cdot = h A\left(T_w - T_b\right) \quad (4)$$

In order to extract the heat by coolant water, the removed heat was measured through Eqn. (5) to calculate the temperature difference of water ΔT as follow [24]:

$$Q\cdot = m\cdot C_P DT \quad (5)$$

Where mass flow rate is solved by Eqn. (6) [25]:

$$m\cdot = r\, v_{avg}\, pD_i^2/4 \quad (6)$$

For electrical modelling, the PV panel efficiency η_{PV} is calculated under AM1.5G standard [26]. The short circuit current is solved by Eqn. (7) [27]:

$$I = I_{sc} - I_{01}\left(e^{q(V+IR_S)/KT} - 1\right) - I_{02}\left(e^{q(V+IR_S)/2kT} - 1\right) - \left(\frac{V+IR_S}{R_{SH}}\right) \quad (7)$$

The open circuit voltage is solved by Eqn. (8) as follow [27]:

$$V_{OC} = n\frac{KT}{q} ln[\frac{I_{PV}}{I_{o1}} + 1] \quad (8)$$

The solar cell efficiency can be presented as shown in Eqn. (9) [27].

$$h_{PV} = \frac{Pout}{Pin} = \frac{V_{OC} I_{sc} FF}{q_{rad}\ A} \quad (9)$$

4. NANO-FLUID PREPARATION

The nanoparticles thermal properties have a particle size of aluminum oxide (AL_2O_3) less than 50 nm. Pure water is used instead of tap water to avoid impurities mixing with nano-particles and lessen the probability of error in the experimental results. The specifications of fluids are used in this work shows in Table 1.

Table (1): Working fluid specifications [28]

Fluid & Materials	Water	Al2O3
Density (kg/m^3)	997.1	3970
Specific heat (J/kg.K)	4179	765
Thermal conductivity (W/m.K)	0.613	40

The nano particles (from MERCK Company) [28] with a molecular weight of 101.96 [29] are added to 10 Litre pure water with a wt% of 0.001, and 0.01, and then placed in an ultrasonic homogenizer for 90 minutes to achieve a uniform distribution (dispersion) in the solution, before it is put to use in the system [29].

The Aim for choosing this type of nano-fluid and these concentrations, that the AL_2O_3 widely uses in the field of PV cooling techniques [29], is cheaper than the other types of nano-particles [15], and available. The concentrations are chosen from the simulation program after adding different concentricity from 0.001 to 0.03 wt%. The simulation shows, from 0.001 wt% to 0.009 wt% the average temperature of PV panel is improved, but the best enhancement is 0.01 wt%. After this concentration, the improvements are unnoticeable change. The density of nano-fluid is solved by Pak and Cho's Eqn. (10) [30].

$$r_{nf} = r_f(1- f) + r_p.f \quad (10)$$

Nano-fluid specific heat is solved by Xuan and Roetzel's Eqn. (11) [4].

$$(C_P r)_{nf} = (C_P r)_f (1- f) + (C_P r)_p f \quad (11)$$

The thermal conductivity of nano-fluid is calculated by Maxwell's Eqn. (12) [31].

$$k_{nf} = k_f \frac{(k_p + 2k_f - 2f k_f - (k_p)}{((k_p + 2k_f + f k_f + (k_p)} \quad (12)$$

The results, of the mixture of AL_2O_3-nano water with different concentrations shown in Table 2.

TABLE (2): Specifications results of nano-fluid with different concentrations [28]

Concentrations	0.001 wt%	0.01 wt%
Density (kg/m^3)	-	1202.5
Specific heat (J/kg.K)	4413.23	5214.12
Thermal conductivity (W/m.K)	0.6122	0.7512

5. PV/T EXPERIMENTAL SETUP.

Figure 3 shows a fixed (PV/T) standalone experimental set-up of three PV modules designed to study the electrical and thermal behaviours for each module. These modules work simultaneously, whereas three tanks and pumps were attached to each module with backside pipes for the fluid's cycle.

The solar irradiance has ranged from 90 W/m^2 to 1200 W/m^2 in the area of experimentation at the Tenth of Ramdan City (31° 74 'E 30° 30'N) [23]. The experiment starts from 6:00 am to 6:00 pm, every 30 minutes during this period a reading is recorded. A solar power meter is used to record the daily global Sun irradiance.

Fig 3: General view for the experimental system [23].

Figure 4 introduces the Pancake shape of the pipe is bonded to each PV module by thermal paste (Type: ARCTIC MX-5 Extremely High Thermal Conductivity) under the PV panel with a thickness of 0.01 m to stuck and transfer the heat to the fluids moved inside the pipes to decrease the module temperature.

Fig 4: A general view for experimental pancake pipes [23].

Figure 5 introduces the general view of each PV module where the sensors are used to collect the data from PV/T system. Infrared thermometer (IR) is used to measure the surface temperature of the PV module at different five points to calculate the average temperature of the panel, also two K-types of thermocouples (Filotronix Company) is used to measure the inlet and outlet temperatures for the fluid cooling used. The pump is applied to circulate the fluid (DC source 12V with 0.4 A) with a maximum power consumption of 4.8 watts and flow range (1 to 12.6 L/min).

This pump is used especially for the PV modules (take the source from PV panel) to decrease the power consumption of the system. The pump intake of the fluid from a cylindrical vertical tank (5.65-liters) with internal dimension (120 mm diameter × 500 mm height) is fabricated, coated, and insulated to store the cooling fluid. The system is needed to cool the PV panel 1.69 Liters (4 m internal & external hose length to pancake shape with 6.18 m the length of the pipe of pancake shape and diameter 12 mm), but in this experimental work is used 4 Liters to avoid tank's empty and gaps (air bubbles) through the cooling path.

The tank has internal stirrer with low power consumption (DC source 12 V with 0.5 A). The stirrer focuses on two important points: mix the nano-fluid with water to prevent its deposition at the bottom of the tank [15] and to make the cooling nano-fluid process faster. The output power electric circuit consists of resistors with different ranges, connected to the voltmeters which measure the PV output power values, and the period to collect the experimental data in August 2022 [15, 16].

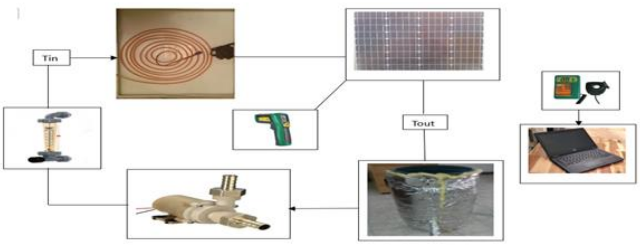

Fig 5: A general view for experimental setup

6. RESULTS AND DISCUSSION.

In order to enhance the current and voltage of the PV modules, water passed underlying pipes. The investigation of the output power depends on specific parameters like the solar irradiance falling on the surface of PV modules, the location of setup [23], etc. but the most important parameters are the cooling water flow rate [11] and the module operating temperature [4].

Figure 6 shows the comparison between simulation and experimental results of solar irradiance ranges, in simulation results the maximum intensity at 12 pm reached to 1200 W/m^2 while with experimental results recorded 1171 W/m^2 [23]. That lead to the radiation amount affected and raised the PV module temperature due to be exposed for a long time to the Sun irradiance.

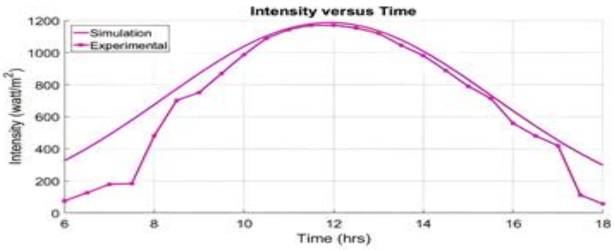

Fig 6: Simulation and experimental readings of Sun irradiance curves during day time [20].

Figure 7 presents a comparison between experimental and simulation results for PV module cooling using water and different concentrations of Al_2O_3/water nano-fluid, in simulation results the average temperature of PV module at 12 pm for water cooling is 49.2 °C compared with the experimental results of 47.7°C. For nano-fluid Al_2O_3/water with concentration 0.001% the simulation result for average temperature at the same time is 46.6 °C, but for experimental results is 45°C. While for nano-fluid Al_2O_3/water with concentration 0.01% the simulation result at 12 pm for average temperature is 42.7°C and the experimental result is 41°C around 14.04 % and 8.8% temperature reduction compared with water and 0.001 wt% Alumina. the main conclusion from the results on the graph is that the highest nano-fluid concentration (Al_2O_3/water with concentration 0.01%) leads to the largest reduction in the temperature of the PV module.

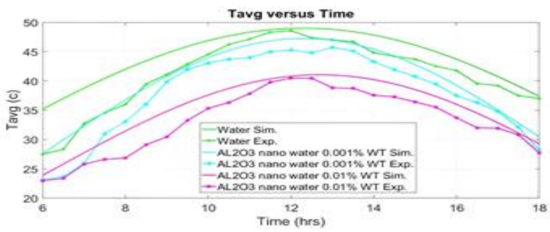

Fig 7: The effect of using water and difference concentrations of Al_2O_3/water on the PV module temperatures [20].

Figure 8 introduces a comparison between simulation and test rig results of temperature difference using water and different concentrations of Al_2O_3/water nano-fluid. in simulation results at 12 pm, for water cooling the difference in temperature is 5.9°C, but in experimental result is 5.8°C. For 0.001 wt% Al_2O_3/water, the simulation difference in temperature result at 12 pm reaches to 7 °C. But for experimental results reaches to 6.9°C. The best improvement shows in 0.01 wt% nano-fluid Al_2O_3/water, the simulation result at 12 pm is 7.5°C. But for experimental results enhancement to 7.4 °C. this presents that the temperature difference for nano-fluid Al_2O_3/water with concentration 0.01 absorb the heat from the PV panel more than the other cooling fluids. the value of improvement for 0.01 wt% nano-fluid Al_2O_3/water 21.6 % and 6.7 % compared with water and 0.001 wt% Alumina. Unfortunately, that performs the ultimate heat transfer as it has the highest temperature difference and that increases the thermal efficiency of the PV module with cooling fluid of 0.01 wt%.

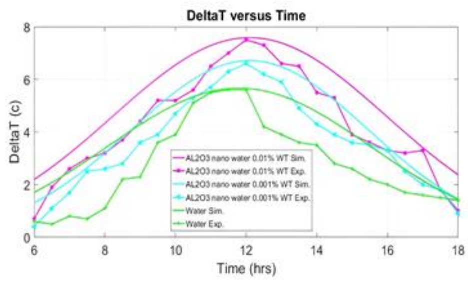

Fig 8: the variation between inlet and outlet temperatures using water and different concentrations of Al_2O_3/ water for PV module [20].

Figure 9 shows a comparison between the output power verses day time simulation and experimental results by utilizing water and different concentrations of Al_2O_3/water nano-fluid on the PV panel cooling. In simulation results at 12 pm for water cooling the output power reaches around 42.7 Watt. But for experimental results reaches around 42 Watt. For nano-fluid Al_2O_3/water simulation results at 12 pm with concentration 0.001% the output power reaches around 47.9 Watt. But for experimental results reaches 47 Watt. For nano-fluid Al_2O_3/water simulation results at 12 pm with concentration 0.01% the output power reaches around 49.3 Watt. But for experimental results reaches 49.2Watt. The main conclusion from the results on the graph is that the best fluid utilized for cooling pancake shape is nano-fluid Al_2O_3/water with concentration 0.01%, as it raises the generated power about 4.5% more than Al_2O_3/water with concentration 0.001%, and about 14.6% more than water cooling method. This enhancement due to the reduction of PV panel temperature that leads to increase in the electrical parameters and in sequence elevates the produced power.

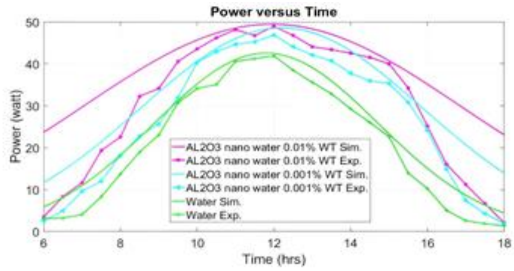

Fig 9: The influence of using water and different concentrations of Al_2O_3/water on the PV generated power [20].

Figure 10 shows a comparison between the efficiency verses day time simulation and experimental results using water and different concentrations of Al_2O_3/water nano-fluid .in simulation results at 12 pm for water cooling the efficiency reaches around 8.4%. But for experimental results reaches around 8.1%. For nano-fluid Al_2O_3/water simulation results at 12 pm with concentration 0.001% the efficiency reaches around 9.5%. But for experimental results reaches about 9%. For nano-fluid Al_2O_3/water simulation results at 12 pm with concentration 0.01% the efficiency reaches around 11.5%. But for experimental results reaches 11.4%. This graph presents that the ultimate general efficiency for PV is being achieved by nano-fluid Al_2O_3/water with concentration 0.01% method of cooling, as it records an increase in the PV efficiency (3.3% and 2.4%) more than water and 0.001 nano-fluid Al_2O_3/water insequance. These improvements due to its high electrical parameters, High specific surface area, and its high thermal conductivity.

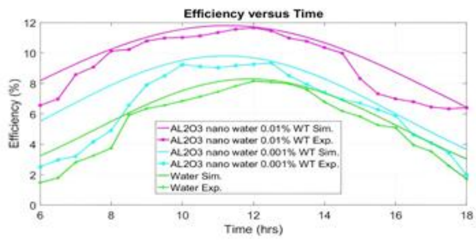

Fig 10: The effect of using water and different concentrations of Al_2O_3/water nano-fluid on the PV module total efficiency along the day time [20].

7. CONCLUSION.

To sum up, this work illustrates the impact of active cooling technique with water and nano-fluid (Alumina) with different concentration (0.001 wt% & 0.01 wt%) as a cooling fluid. The pancake shape presents as a new shape of pipes to target the maximum thermal heat transfer that leads to increase the output power of PV module performance. The main conclusions are optimized as follows:

- The module temperature with 0.01 wt% AL_2O_3-nano fluid decreased about 14.04 % and 8.8 % compared with water and 0.001 %wt of the same nano water.
- The investigation in the difference between input and output cooling fluids temperatures presented an increase in ΔT for Alumina with a concentration of 0.01 wt% around 21.6 % for water and 6.7 % for 0.001 wt% AL_2O_3-nano fluid.
- This enhancement increased the maximum output power by about 42 watts for water cooling, 47 watts for 0.001 wt% AL_2O_3-nano fluid, and 49.2 watts for Alumina with a concentration of 0.01 %wt.
- The best enhancement in PV/T system efficiency was 11.4% for Alumina with a concentration of 0.01 %wt.
- The collected data and the results showed that the 0.01 %wt AL_2O_3-nano fluid is the best PV/T system performance compared with the PV/T system using other cooling fluids.

NOMENCLATURE:

Symbol	Description	Units
υ_{avg}	The average velocity inside the channel	m/s
D	The channel diameter	m
γ	The Kinematic viscosity	
ΔP	The measured pressure drop	Pa
F_D	The Darcy Friction factor	----
ρ	The fluid density	Kg/m^3
L	The pipe length	m
$Q_{emitted}$	The emitted heat	W/m^2
ε	The Emissivity	----
σ	The Stefan-Boltzmann constant	5.669×10^{-8} $W.m^{-2}.K^{-4}$
T_{PV}	The PV temperature	K
T_{amb}	The Ambient temperature	K
h	The convective heat transfer coefficient	$W/m^2.K$
T_W	The PV surface average temperature	K
A	The body area	m^2
T_b	The average temperature of coolant (K) which is defined as (Tout + Tin) / 2	K
$Q^\bullet$	the removable heat	Watt
$m^\bullet$	The mass flow rate	Kg/s
ΔT	The inlet and outlet fluid temperature difference	K
I_{SC}	The short circuit current	A
I_{01}	The Dark saturation Current	A
R_S	The series resistance	ohm
K	Boltzmann constant	$1.38 \times 10^{(-23)} m^2. kg.s^{(-2)}.K^{(-1)}$
I_{02}	The Reactive current	
R_{SH}	The shunt resistance	ohm
V_{OC}	The open circuit voltage	Volt
n	The Ideality Factor	----
q	The electron charge	$1.6 \times 10^{-19} C$
η_{PV}	PV efficiency	%
P_{out}	Power output	W
P_{in}	Power output	W
ρ_{nf}	nano-fluid density	$(Kg/m^3) m^3$
ρ_f	cooling fluid density	$(Kg/m^3) m^3$
ρ_p	nano-particles density	$(Kg/m^3) m^3$

∅	Volume concentration	%
c_{pnf}	Specific heat of nano-fluid	J / kg.K
c_{pf}	Specific heat of cooling-fluid	J / kg.K
c_{Pp}	Specific heat of nano-particles	J / kg.K
k_{nf}	Thermal conductivity of nano-fluid	W / m.K
k_f	Thermal conductivity of nano-fluid	W / m.K
k_p	Thermal conductivity of nanoparticles	W / m.K

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