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EXPERIMENTAL AND NUMERICAL STUDY ON NANOFLUID COOLING OF PV SOLAR PANELS

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ABSTRACT

One of the main factors that affects the efficiency of photovoltaic (PV) panels while generating power is their temperature throughout the day. When the cell temperature increases, the generated power and the efficiency decreases. In this study, experimental and numerical approaches are carried out to examine the effect of adding Al_2O_3 nanofluid on the performance of PV panels compared to pure water. Two modules are used in this study, the first one is uncooled PV panel, and the second module is used for both water and nanofluid cooling medium flowing through a pancake copper coil configuration. The pancake coils are attached to the back side of the PV panels. The concentration of nanofluid that is considered for the evaluation is (0.001 Al_2O_3). ANSYS software was used to simulate and determine the thermal performance of both cooling methods in order to compare with experimental results. As expected, there is an enhancement in the efficiency of the cooled module compared to the uncooled module, which helps to increase the output power. The results showed the output power for the nanofluid water-cooled panel increased by 15.6% compared to that cooled with water. The heat transfer fluid containing (0.001 Al_2O_3) improved PV panel performance by lowering PV temperature.

1. Introduction

Solar energy has been increasingly popular as an economical, clean, and sustainable energy source. Solar photovoltaic technologies are employed for power generation [1,2]. Excessive heat decreases the efficiency and output of solar panels [3]. In hot regions, the high ambient temperatures lead to insufficient heat dissipation from solar PV modules. This results in a comparatively higher PV module temperatures owing to heat accumulated in the PV panels [4,5]. During the hours of intense sunlight on hot days, elevated temperatures negatively impact the efficiency of solar photovoltaic modules [6,7]. Zaraket et al. [8] proposed a study that determined the influence of temperature on the electrical properties of solar photovoltaic modules. The results showed that PV modules exposed to fluctuating temperatures during daylight and nighttime experience changing degrees of electrical stress, which negatively impacts the forward and reverse I–V characteristics of the PV panel. Huang et al. [9] found that solar cells' open circuit voltage (V_{oc}) and short circuit current (I_{sc}) pose a significant risk to solar PV module power generation. Temperatures exceed design limits, together with other environmental factors, including wind speed and direction.

Research has been performed utilizing various thermal management approaches to enhance the efficiency and power output of solar photovoltaic modules [10,11]. Ramkiran et al. [12], investigated the enhancement of electrical production and the reduction of temperature in a 50 W polycrystalline photovoltaic module by various cooling techniques, including plant cooling, greenhouse cooling, greenhouse plant cooling, Coir pith, and phase change material cooling. The cooling with Coir pith demonstrated the highest percentage increase in power of more than 11.34%. Talib K. Murtadha et al. [13] presented three active cooling techniques employing nano fluid Titanium Oxide at concentrations of 1 wt%, 2 wt%, and 3 wt%, in comparison to water cooling and photovoltaic cooling methods. The findings indicate generated power outputs of 39.5 W, 42.6 W, 43.2 W, 44 W, and 44.5 W for PV cooling, water cooling, and the various concentrations of nano fluid Titanium Oxide 1wt%, 2 wt%, and 3 wt%. Aberoumand et al. [14] Presented a 35.0% enhancement in the efficiency of a solar

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PV/T system when the panel was cooled using an Ag/water nanofluid medium compared with PV cooling. Sardarabadi and Passandideh-Fard et al. [15] conducted an experimental and computational investigation comparing three distinct metal oxides: ZnO, TiO_2, and Al_2O_3.The optimal thermal efficiency of a PV/T system was achieved using ZnO-water nanofluid. S Deivakumara et al. [16] results indicate that silver nanofluid exhibits a 12.66% superior power efficiency compared to water. Al-Waeli, et al. [17] used SiC water nanofluid as the basis fluid for photovoltaic cooling. Incorporating 3% by weight of SiC into water elevated the density and viscosity of the liquid to 0.0082% and 1.8%, respectively. An enhancement in thermal conductivity of up to 8.2% was attained, hence augmenting the heat transfer capabilities. The photovoltaic temperature diminished by 16 °C, while the enhancement in electrical efficiency was 24.12%. Afroza Nahar [18] performed a computational study on a 3D model using numerical analysis to investigate the performance of the photovoltaic system with a pancake-shaped pipe attached to the rear of the photovoltaic module. The results indicated that the temperature of the photovoltaic module decreased by about 8°C relative to the system without cooling, and a 2% enhancement in PV efficiency when the input velocity was altered from 0.0009 to 0.05 m/s.

This study experimentally and numerically compares cooling method utilizing water and nano water 0.001%wt Al_2O_3 passing through pancake coil to investigate of adding nanofluid to water. The concentration and the specific nanofluid, AL_2O_3, are selected due to their extensive utilization in solar cooling methods. Its cost-effectiveness relative to other nanoparticle kinds, as well as its availability.

1. Experimental setup

Experimental; setup was built to investigate the effect of adding nanofluid on the colling of the PV compared to water cooling. **Figure 1** illustrates the experimental configuration for the fixed setup, including two 50-Watt photovoltaic panels system all of size (670×540×25 mm), positioned at a 30-degree inclination facing south. The first panel is without cooling, the second is used for water or nano water-cooled using pancake coil. The experiments were conducted from 6:00 AM to 6:00 PM, with measurements recorded every 30 minutes. The measured solar irradiation was varied from 42 W/m² to 825 W/m² along the day.

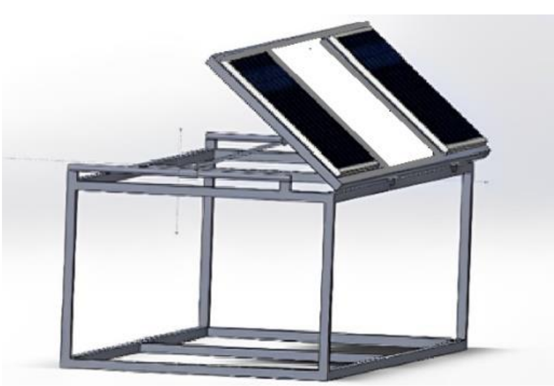
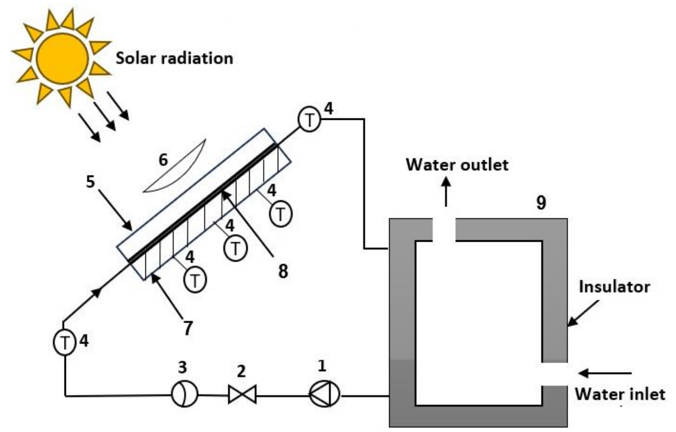


Figure 1: The three modules of the fixed experimental setup

The liquid cooling PV module has pancake coil, tank, pump, valve, flowmeter and connecting pipes for the fluid cycle, as shown in **Figure 2**. The pancake coil of length 9 m and 0.25-inch-diameter copper pipes is fitted at the back of the solar panel. Copper is utilized for its excellent thermal conductivity and its ability to be shaped as needed easily. The average flow velocity is consistently 6 l/min.



1. Pump 2. Valve 3. Flow meter 4. Temperature sensors 5. PV cell 6. Pyrometer 7. Insulation 8. Pancake coil 9. Water tank

Figure 2: Schematic of the PV module water cooling system and pancake copper coil

2. Nanofluid preparation

The thermal properties of the nanoparticles indicated that the particle size of aluminum oxide (AL_2O_3) is less than 40 nm. Pure water is employed instead of tap water to minimize experimental errors and prevent contaminants from interacting with the nanoparticles. Table 1 presents the fluid parameters utilized in this study:

Table1.Working fluid specifications [19]

Fluid property	Water	Nano fluid (Al_2O_3)
Density (kg/m^3)	997.1	3970
Specific heat (J/kg.K)	4179	765
Thermal conductivity (W/m.K)	0.613	40

The nanoparticles with a molecular weight of 101.96 g/mole are included in 10 liters of clean water at a wt% of 0.001. Before being used in the system, they are put through a 90-minute homogenizer cycle to ensure a uniform distribution (dispersion) in the solution. The stability of the nanofluid combination was evaluated by capturing images on the initial day of mixing and after three days. The reason for choosing these concentrations and this specific nanofluid, namely AL_2O_3, is its widespread application in photovoltaic cooling techniques [20]. Its cost-effectiveness compared to other nanoparticle types, because Al_2O_3 nanoparticles are cheap compared to other nanoparticles, they are also easy to find and are produced in big quantities. While keeping costs low, Al_2O_3 is better at durability and better than other nanofluid solutions in thermal [21].

3. Numerical analysis

3.1 Ansys model setup description

Ansys Multiphysics used a finite element method to develop the numerical simulation model for the cooling technique. In this study, the proposed system comprises a solar panel featuring 32 cells, with 540 × 670 × 25 mm dimensions, constructed from polycrystalline silicon. It is encased in an aluminum plate that matches the dimensions of panels with a thickness of 25 mm, utilizing 3724973 mesh elements, as illustrated in **Figure 3**.

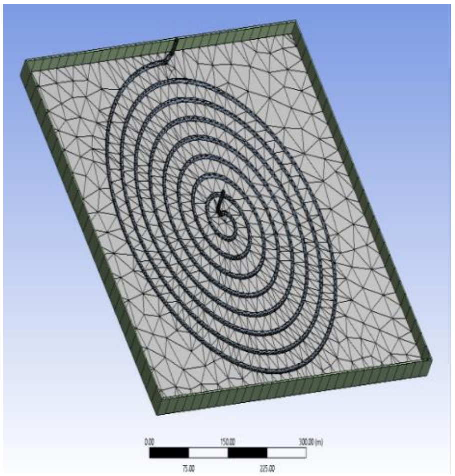


Figure 3: The PV modules using Pancake coil.

3.2 Ansys governing equations

A numerical simulation of the flow field within a three-dimensional PV is employed to investigate and address the complexities of fluid flow and heat transfer models. This work utilizes the commercial program Fluent 14.5 as the CFD tool. The numerical calculations were executed by resolving the governing conservation equations with the boundary conditions using the finite volume technique (FVM). The 'SIMPLE' algorithm manages the pressure-velocity relationship. The numerical simulation employs the RNG k-ε turbulence model alongside the Enhanced Wall Treatment model to investigate the flow field phenomena in a plain tube with a rough surface. The applied boundary conditions consisted of a radiation coefficient of 0.8 and a convection coefficient of 30 W/m²·K for both the top and lower surfaces. The photovoltaic system receives a fluctuating heat flux ranging from 42.43 W/m² to 825 W/m². The fluid velocity was 6 L/min, the inlet temperature of the fluid was around 20°C, and the Reynolds number was 22500.

Equation of continuity:

$$\frac{\partial(\rho\, u_i)}{\partial x_i} = 0 \quad (1)$$

Momentum equation:

$$\frac{\partial(\rho\, u_i u_j)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial(u_i)}{\partial x_j} + \frac{\partial(u_j)}{\partial x_i}\right) - \overline{\rho\, \acute{u}_i \acute{u}_j}\right] - \frac{\partial p}{\partial x_i} \quad (2)$$

Where,

$$-\overline{\rho\, \acute{u}_i \acute{u}_j} = \mu_i\left(\frac{\partial u_i}{\partial x_i} + \frac{\partial u_j}{\partial x_j}\right) - \frac{2}{3} K \delta_{ij}$$

Energy equation:

$$\frac{\partial}{\partial x_i}[\mu_i(\rho E + p)] = \frac{\partial}{\partial x_i}\left(K_{eff}\frac{\partial T}{\partial x_i}\right) \quad (3)$$

3.3 Grid-Dependent analysis

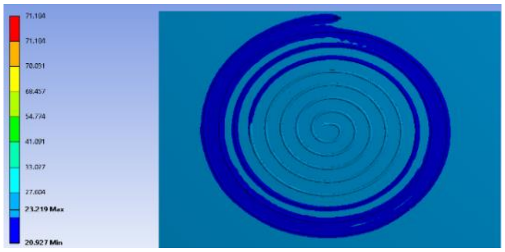
To create a mesh that covers every surface, tetrahedral meshes are utilized. The grid-independent test is often used to verify that an identical mesh quality is achieved, and the results stay constant regardless of the grid size and the quality. For this study, the grid independence test was carried out using PV with and without cooling. Five grid densities of about 1189426,2594738 are calculated for 3601800, 3724973, and 5321467 cells. Water serves as the working fluid, with a Reynolds number of 22500, the PV dimensions was 670mm×540mm×25mm, the cupper coil was with 6.35 mm diameter, 0.5 mm thickness, Enhancing the amount of mesh elements from 3,724,973 to 5,321,467 does not influence the temperature. Therefore, the 3,724,973-element grid is ideal for computational models**.**

4. Results and Discussion.

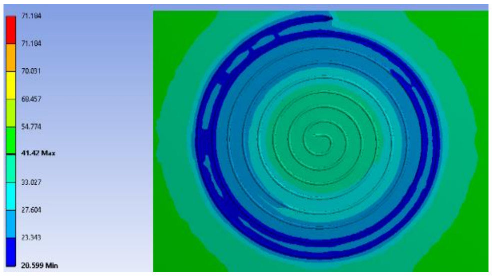
This part represents the results carried out experimentally and the results extracted from CFD analysis using the Ansys numerical software program for both cooling methods that is explained in the text.

4.1. Modeling results

The results carried out from Ansys program for only water cooling are shown in **Figure 4**. The input water temperature was established at 20 °C, with a flow rate of 6 L/min. The recorded average temperatures were 20.98 °C, 31.84 °C, 39.29 °C, 45.78 °C, 48.46 °C, 46.07 °C, 37.79 °C, and 29.39 °C at 6 am, 8 am, 10 am, 12 pm, 1 pm, 2 pm, 4 pm, and 6 pm, respectively. This data indicates a progressive increase in average temperature throughout the day, peak one was at 1 pm, followed by a decline until the day's end. When compared to non-cooled PV, the pancake cooling method proved superior. It reduces the average temperature by 0.19 °C, 5.46 °C, 12.45 °C, 14.67 °C13.69 °C, 12.59 °C, 7.75 °C, and 3.91°C along the day, this is due to the difference between the temperature of the inlet water and solar panel temperature and also due to its extensive cooling effective area. Also, the turbulence in fluid dynamics, which increases heat transmission and the heat transfer coefficient, hence improving PV cooling.



6 am



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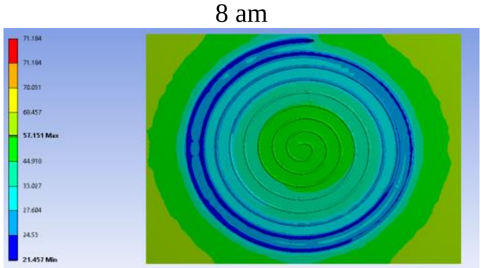

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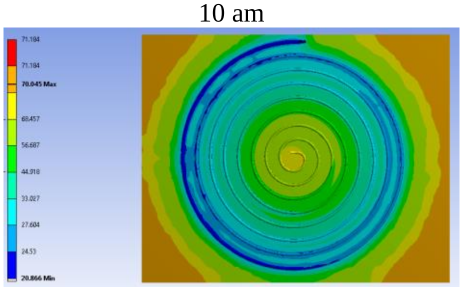

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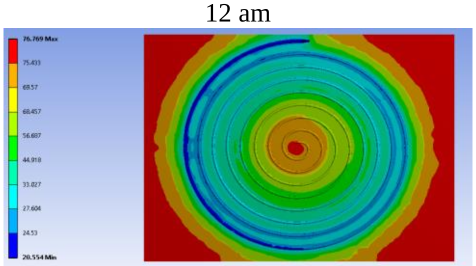
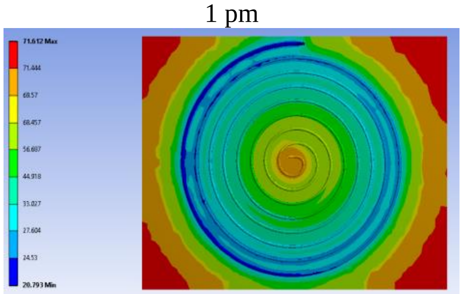


1 pm



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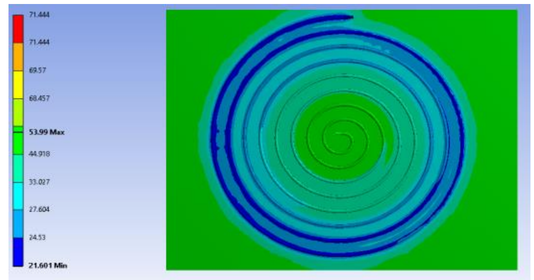

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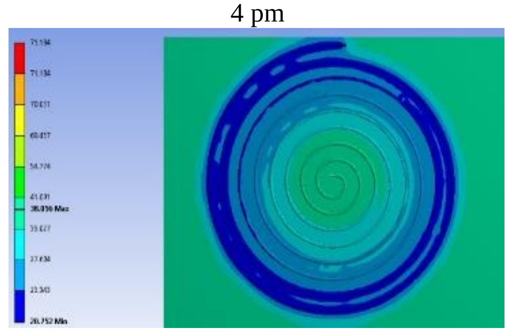
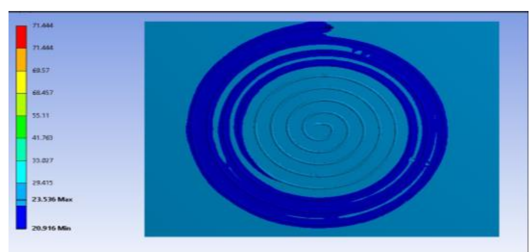


6 pm

Figure 4: CFD analysis for pancake using water as a cooling fluid.

Figure 5 presents the outputs of CFD analysis executed with the Ansys program for the pancake method using Al_2O_3/water at a concentration of 0.001%. The flow rate of the water/nanofluid was 6 L/min. The average temperatures recorded at the same time interval of water cooling (i.e., from 6 am, to 6 pm with step of two hours) were 20.7 °C, 31.4 °C, 38 °C, 43.6 °C, 46.29 °C, 44.67 °C, 34.5 °C, and 28.4 °C, respectively. The temperature differences compared to water were 0.28 °C, 0.44 °C, 1.29 °C, 2.18 °C, 2.17 °C, 1.4 °C, 3.29 °C, and 0.99 °C. This improvement in the average temperature of the PV is due to the superior heat transfer capabilities of the nanofluid relative to water. Additionally, fluid dynamics turbulence improves PV cooling by raising the heat transfer coefficient and heat transmission.



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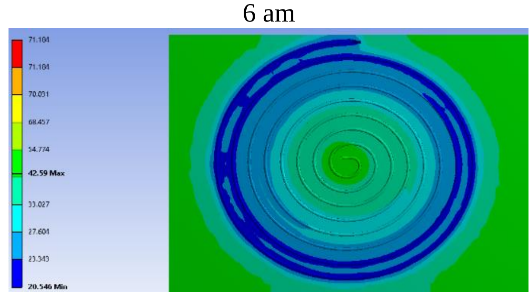

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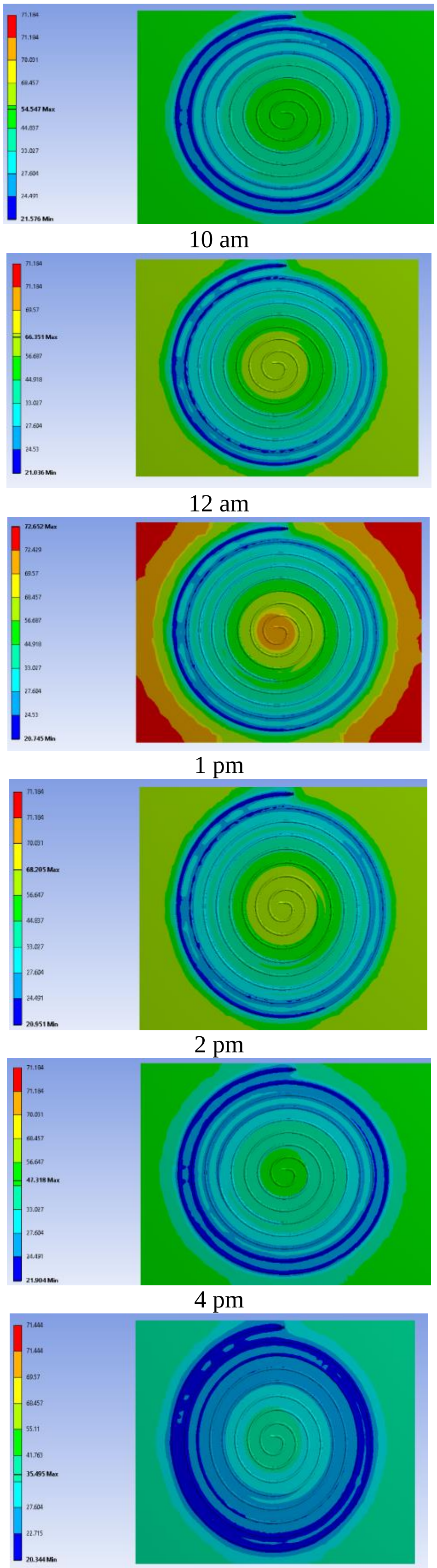

Figure 5: CFD analysis pancake method by using Al_2O_3/water with concentration 0.001% as cooling fluid.

4.2. Comparison between Numerical Model and Experimental Work.

Figure 6 illustrates the reduction in photovoltaic (PV) temperature resulting, at 1 PM when solar irradiation was around 789 W/m². In the pancake method using water as a cooling fluid the experimental PV temperature is about 47.37 °C, while the theoretical result is approximately 48.4 °C. While for pancake method using nanofluid AL_2O_3 with concentration 0.001% experimentally the PV temperature was 45.76°C, while in simulation the PV module temperature was about 46.29 °According to the curves, the pancake with 0.001 AL_2O_3 concentration exceed the only water cooling. This nanofluid lowers the PV temperature by 1.61°C in the test rig and 2.11°C in simulation results than pancake method using water as a cooling fluid, with reductions of about 3.39% and 4.35% in sequence. Thus, providing the largest cooling surface when the dimensions of the PV module are identical. Moreover, turbulence in fluid dynamics improves photovoltaic cooling by enhancing the convection heat transfer coefficient and thermal conductivity.

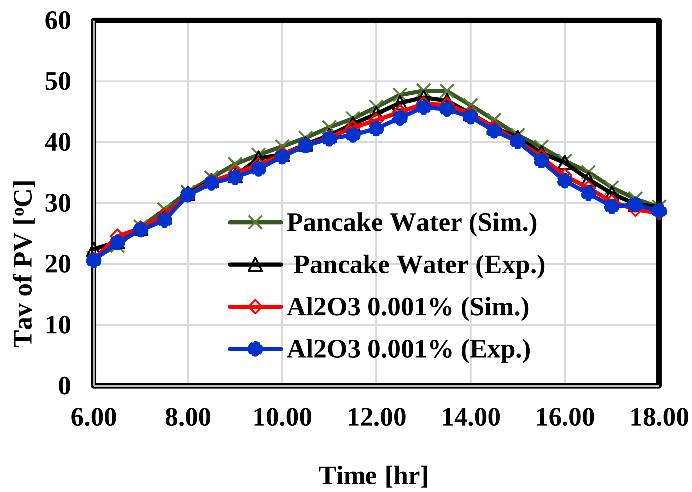

Figure 6: The comparison between modules average temperatures verses daytime (Experimentally and Simulated).

Figure 7 compares simulation results and experimental data regarding the fluctuations in inlet and outlet water temperatures throughout the daytime for Pancake pipe configurations on July 14, 2022. The temperature variations recorded were approximately 5.6 °C for pancake pipe using water as a cooling fluid and 6.67 °C for Pancake using 0.001 %AL_2O_3 during the peak operational hour at 1 pm. Furthermore, the modeling results indicated that the temperature difference of the cooling fluid (water) at the intake and outlet was 5.69 °C and 6.75 °C, respectively, during the peak operational hours of the day. This higher temperature difference for the pancake method is due to its higher effective area, which results in higher thermal conductivity and higher convection heat transfer coefficient.

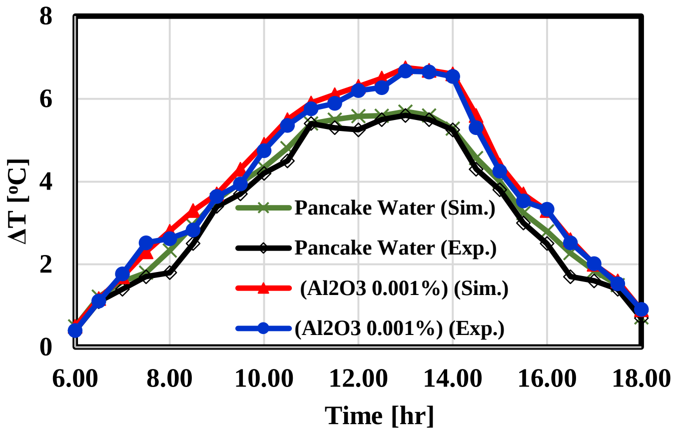

Figure 7: a comparison between simulation & experimental results of temperature difference between inlet and outlet temperatures of water and 0.001 %AL_2O_3 for pancake shape of pipe.

Figure 8 compares modeled and experimental data for photovoltaic produced power throughout the daytime for water and nanofluid technique flowing via pancake coil mounted at the panel's rear side. This curve illustrates output generated power. The output generated power measured at midday (peak solar radiation) was the maximum generated power. It was around 40.9 W, and 42.44 W for water and 0.001 %AL_2O_3 nanofluid respectively. The simulation results also indicates that the generated power was around 40.7 W, and 42.3 W for water and nanofluid cooling methos. The reason for the increase generated power while using 0.001 %AL_2O_3 nanofluid is that it has the most effective area. Also, turbulence in fluid dynamics enhances photovoltaic cooling by increasing the convection heat transfer coefficient and thermal conductivity. This led to an increase in electrical characteristics.

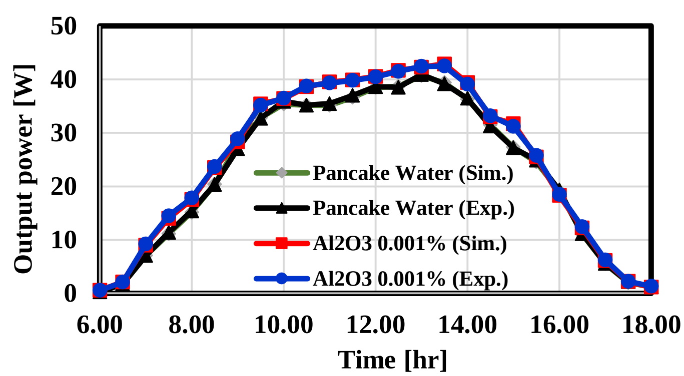

Figure 8: A comparison between simulation & experimental results of power versus daytime curves pipes using water and 0.001 %AL_2O_3.

Figure 9 compares the efficiency between daylight modeling and experimental results utilizing water and 0.001% Al_2O3/water nanofluid as cooling methods. At noon, the simulation findings for water as a cooling fluid indicate that, the efficiency reaches 14.26%, and experimentally reaches about 14.33%. The efficiency of the simulation findings for Al_2O3/water nanofluid at a concentration of 0.001% at noon is around 14.87%, whereas the test rig results were about 14.82. This comparison demonstrates that the nanofluid Al_2O_3/water achieves the highest overall PV efficiency, due to Its superior electrical characteristics, extensive specific surface area, and elevated thermal conductivity result in the increase of the PV efficiency.

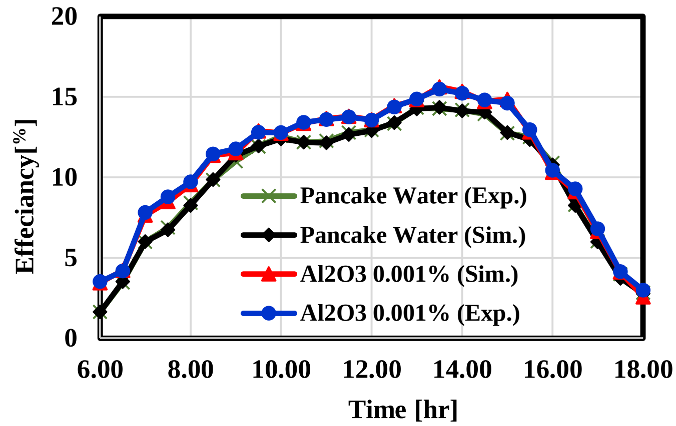

Figure 9: The effect of using water and nanofluid 0.001 concentration of Al_2O_3 on the PV module total efficiency along the daytime.

5. Conclusions

The principal conclusions have been defined as follows:

- The pancake utilized nano fluid (0.001 wt% Al_2O_3) as a cooling fluid at a flow rate of 6 l/min., at a solar intensity of around 789 W/m² at 1 pm, has seen the greatest drop in the average temperature of the photovoltaic system in comparison to only water cooling.
- The pancake employing nanofluid water (0.001 wt% Al_2O_3) as a cooling fluid, results in a lower average PV temperature of 46.29 °C, compared to, 48.46 °C for the pancake only water cooling.
- The water nanofluid (0.001 wt% Al_2O_3) resulted in the most significant drop in the average PV temperature at 1:00 pm. It reaches approximately 46.29°C, which is 4.47% lower than that of water cooling.
- The output generated power increases when using (0.001 wt% Al_2O_3) nanofluid by 1.54 W.
- The (0.001 wt% Al_2O_3) nanofluid has the highest total photovoltaic efficiency. Theoretically it is about 14.82%, and experimentally it is about 14.87%. It is higher than only water cooling by approximately 0.5%.

References

[1] Abdulhadi Abdallah, Richard Opoku, Charles K.K. Sekyere, Samuel Boahen, Kofi O. Amoabeng, FelixUba, GeorgeY.Obeng, FrancisK.Forson, "Experimental investigation of thermal management techniques for improving the efficiencies and levelized cost of energy of solar PV modules", Engineering, Volume, July 2022.

[2] Nasrin Abdollahi, Masoud Rahimi, "Potential of water natural circulation coupled with nano-enhanced PCM for PV module cooling", Renewable Energy ,Volume 147, Part 1, March 2020.

[3] Tresna Dewi, Ahmad Taqwa, Carlos Sitompul, R D Kusumanto, Rusdianasari," Active and Passive Cooling Comparison of PV Panels Applied in Tropical City": Case Study Palembang, South Sumatra, IOP Conf. Ser.: Earth Environ 2021.

[4] Mc G. Delgado, J.S. Ramos, S.´ A. Domínguez, "Using the sky as heat sink: climatic applicability of night-sky based natural cooling techniques in Europe", Energy Convers. Manag. 225 (1) (2020).

[5] N.A.S. Elminshawy, M. El Ghandour, H.M. Gad, D.G. El-damhogi, K. El-Nahhas, M.F. Addas, "The performance of a buried heat exchanger system for PV panel cooling under elevated air temperatures", Geothermics 82 (2019).

[6] S. Koundinya, N. Vigneshkumar, A.S. Krishnan, "Experimental study and comparison with the computational study on cooling of PV solar panel using finned heat pipe technology", Mater. Today Proc. 4 (2) (2017).

[7] A. Maleki, A. Haghighi, M. El Haj Assad, I. Mahariq, M. Alhuyi Nazari, "A Review on the Approaches Employed for Cooling PV Cells", Solar Energy, vol. 209, Elsevier Ltd, Oct. 01, 2020.

[8] J. Zaraket, T. Khalil, M. Aillerie, G.A. Vokas, C. Salame, "The effect of electrical stress under temperature in the characteristics of PV solar modules", Energy Proc. 119 (Jul. 2017).

[9] B.J. Huang, et al., "Solar Cell Junction Temperature Measurement of PV Module", PROGRESS IN PHOTOVOLTAICS: RESEARCH AND APPLICATIONS, Vol. 85, 2011.

[10] Z. Peng, M.R. Herfatmanesh, Y. Liu, "Cooled solar PV panels for output energy efficiency optimization", Energy Convers. Manag. 150 (Oct. 2017).

[11] H. Alizadeh, A.M. Nazari, R. Ghasempour, M.B. Shafii, A. Akbarzadeh, "Numerical analysis of photovoltaic solar panel cooling by a flat plate closed-loop pulsating heat pipe", Sol. Energy 206 (2020).

[12] Ramkiran B ,Sundarabalan CK, K.Sudhakar, "Sustainable passive cooling strategy for PV module: A comparative analysis, Case Studies in Thermal Engineering", Volume 27, October 2021.

[13] Talib K. Murtadha , Ali A. dil Hussein, Ahmed A.H. Alalwany , Saad S. Alrwashdeh, Ala'a M. Al-Falahat, "Improving the cooling performance of photovoltaic panels by using two passes circulation of titanium dioxidena nofluid", Case Studies in Thermal Engineering, Volume 36, August 2022.

[14] S. Aberoumand, S. Ghamari, B. Shabani, "Energy and exergy analysis of a photovoltaic thermal (PV/T) system using nanofluids: an experimental study", Sol. Energy 165 (May 2018).

[15] M. Sardarabadi, M. Passandideh-Fard, "Experimental and numerical study of metal-oxides/water nanofluids as coolant in photovoltaic thermal systems (PVT)", Sol. Energy Mater. Sol. Cells 157 (2016).

[16] S Deivakumaran, Y L Chua and Y Y Koh, "Active cooling system for solar panels with silver nanofluid and water", IOP Conf. Series: Earth and Environmental Science 120, Selangor, Malaysia, 2023.

[17] A.H.A. Al-Waeli, K. Sopian, M.T. Chaichan, H.A. Kazem, H.A. Hasan, A.N. Al-Shamani, "An experimental investigation of SiC nanofluid as a base-fluid for a photovoltaic thermal PV/T system", Energy Convers. Manag. 142 (2017).

[18] Nahara A, Hasanuzzamana M, Rahim N A "A 3D comprehensive numerical investigation of different operating parameters on the performance of a PVT system with pancake collector", (Journal of Solar Engineering, ASME) pp. 2017.

[19] MERCcompanysite https://www.merckmillipore.com/IE/en/search/al2o3%20nano?search=&TrackingSearchType=SB+-+Search+Box&SearchContextPageletUUID=&SearchTerm=al2o3+nano

[20] Talib K. Murtadha , Ali Adil Hussein , "Optimization the performance of photovoltaic panels using aluminum-oxide nanofluid as cooling fluid at different concentrations and one-pass flow system", Results in Engineering,Volume 15, September 2022.

[21] H. A. Hasan, J. S. Sherza, L. Abdulrudah Abd, K. A. Ameen, A.M. Abed, A.A. Hatem, K. Sopia "Study the effect of flow water/AL2O3 nanofluid inside mini-channel for cooling concentrated multi-junction" (Global dijital center Frontiers in Heat and Mass Transfer (FHMT), Iraq, 2022.

[22] M. Uzunoglu, M. S. Alam, "Dynamic modeling, design, and simulation of a combined PEM fuel cell and ultracapacitor system for stand-alone residential applications" IEEE Trans. Ener. Conv., **21**(3), 767–775, 2006. https://doi.org/10.1109/TEC.2006.875468

Abbreviation and symbols

Symbol	Description	Units
ρ	Density	Kg/m^3
δ_{ij}	**The Kroneker delta, equal 1 when i=j and 0 otherwise**	-
μ	**Dynamic Viscosity**	**$N.s/m^2$**
μ_i	**Effective dynamic viscosity i-th direction**	**$N.s/m^2$**
E	**Specific internal energy**	**J/kg**
K	**The turbulent kinetic energy**	**J**
K_{eff}	**Effective thermal conductivity of fluid**	**W/m.K**
n	**Performance criteria**	**-**
p	**Local pressure**	**N/m^2**
$u_i u_j$	**Velocity components in i-th & j-th directions**	**m/s**
$(\acute{u_i}\ \acute{u_j})$	**Renolds stress tensor**	
T	**Temperature**	**K**
T_{av}	**Average temperature of the PV cell**	**ºC**
x_i & x_j	**Spatial coordinates**	**m**