FOREX Publication
Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 3 | Pages 1036-1043 | e-ISSN: 2347-470X

Comparative Study of Photovoltaic Thermal Performance with Water and Aloe Vera Heat Extracting Fluids

Kakada Sovan[1*], Rithy Kong[2], Sovannarith Hut[3], Sokna San[4], Chivon Choeung[5], and Chanmoly Or[6]
[1,2]Graduate School, National Polytechnic Institute of Cambodia, Phnom Penh, Cambodia; kakadasovan@npic.edu.kh[1], kongrithyitc@gmail.com[2]
[3,4,5]Faculty of Electricity, National Polytechnic Institute of Cambodia, Phnom Penh, Cambodia; hutsovannarith@npic.edu.kh[3], sansokna@npic.edu.kh[4], choeungchivon@npic.edu.kh[5]
[6]Research and Innovation Center, Institute of Technology of Cambodia, Phnom Penh, Cambodia; or.molyitc@gmail.com

*__Correspondence:__ Kakada Sovan ; *kakadasovan@npic.edu.kh*

ABSTRACT- Crystalline solar panels are widely used in households and for public road lighting. Mono-crystalline panels are well-known for their higher efficiency and long service life. However, their efficiency decreases as the module temperature increases under consistent solar radiation conditions. To enhance module power generation and efficiency, effective temperature reduction techniques are necessary. This study investigates the use of water and aloe vera fluid as cooling agents for a mono-crystalline photovoltaic thermal (PVT) system. The system was designed with a circulating mass flow rate of 0.016 kg/s or 1 LPM (liter per minute) and tested under the climate conditions of Phnom Penh city, Cambodia. The specific heat of aloe vera fluid was determined and found to be 4236 j/kg·K. The optical efficiency of PVT systems using water and aloe vera fluid was compared in this paper. The experiment results indicate that cooling with aloe vera fluid led to a 0.21% higher electrical power generation compared to water cooling, due to more effective temperature reduction and thermal heat absorption rate of aloe vera fluid is higher than water 32.41%.

Keywords: Photovoltaic thermal; Aloe vera fluid; Water; Heat transfer; Mono crystalline.

ARTICLE INFORMATION

Author(s): Kakada Sovan, Rithy Kong, Sovannarith Hut, Sokna San, Chivon Choeung and Chanmoly Or;

Received: 17/07/2024; **Accepted**: 03/09/2024; **Published**: 10/09/2024;
e-ISSN: 2347-470X;
Paper Id: IJEER 1707-27;
Citation: 10.37391/ijeer.120338
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-12/ijeer-120338.html

1. INTRODUCTION

In the quest for sustainable energy solutions, photovoltaic (PV) technology has emerged as a significant player in the global energy landscape. PV systems convert sunlight directly into electricity using semiconductor materials, offering a clean and renewable energy source. However, one of the critical challenges associated with PV systems is their efficiency, which is highly dependent on operating temperature [1]. As the temperature of PV cells increases, their electrical efficiency decreases, leading to reduced overall performance. This thermal issue has led to the development of photovoltaic thermal (PVT) systems, which aim to improve efficiency by simultaneously generating electrical and thermal energy [2].

PVT systems are hybrid configurations that integrate photovoltaic and thermal components. They not only generate electricity but also harness the thermal energy produced during the PV conversion process [3]. This dual approach mitigates the overheating problem and enhances the overall energy yield of the system. The thermal energy extracted can be used for various applications, such as heating water or air, thereby improving the overall efficiency and economic viability of the system [4].

The choice of heat-extracting fluid in PVT systems plays a crucial role in determining their performance. Traditionally, water has been the most commonly used heat transfer fluid due to its high specific heat capacity, availability, and cost-effectiveness [5]. Water's ability to absorb and transfer heat efficiently makes it an ideal candidate for cooling PV cells and extracting thermal energy. However, water also has limitations, such as the potential for freezing in cold climates and the need for regular maintenance to prevent scaling and corrosion.

Research has been directed toward exploring alternative heat-extracting fluids that can offer better performance characteristics. In his research, Prakash conducted a theoretical study on a hybrid photovoltaic thermal (PV/T) solar system, developing a mathematical model based on energy balance equations to predict system performance [6]. A novel heat pipe PV/T system using R600a as a working fluid has been proposed in [7] to improve photovoltaic conversion efficiency compared to traditional water thermosiphon systems. Furthermore, [8] conducted a comparative analysis between water and nanofluids as working fluids in photovoltaic thermal collectors. In addition to that, a comparative study of indirect photovoltaic thermal solar-assisted heat pump systems for industrial applications has been discussed in [9]. A novel configuration of solar concentrating receivers using nanofluids and an Organic Rankine Cycle for heat recovery, showing improved efficiencies compared to traditional CPV/T systems has been discussed in [10]. Using nanofluid and air simultaneously, [11] suggested a dynamic model for a dual-fluid PV/T. Alternatively, [12] investigated the application of aloe vera-based CuO nanofluid as an additive in water-based drilling fluid to improve rheological and filtration properties. To summarize, these studies highlight the importance of exploring different working fluids and system configurations to enhance the performance of photovoltaic thermal systems.

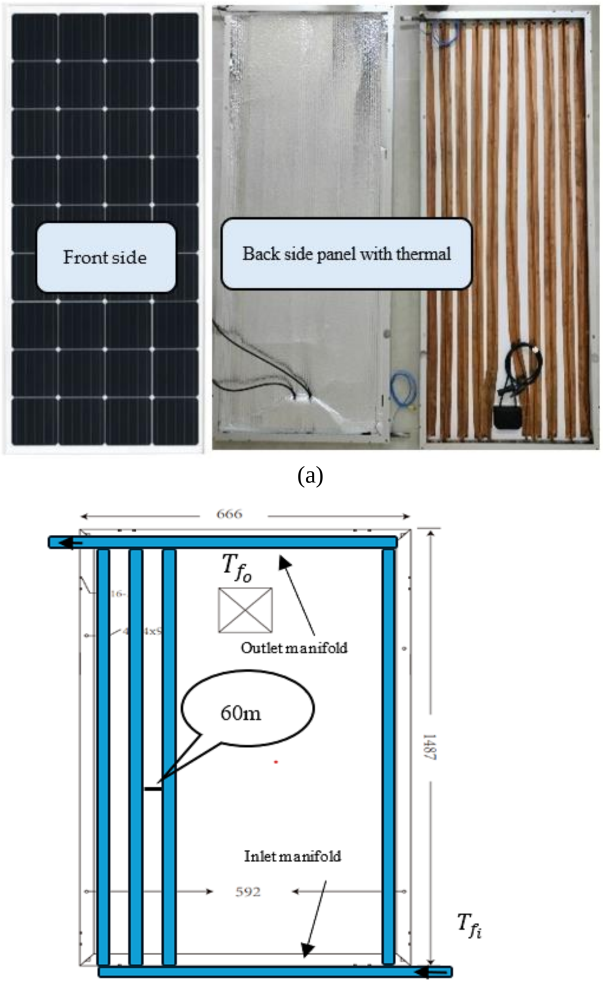
The use of Aloe Vera gel as a heat-extracting fluid in PVT systems is a novel concept that has garnered interest due to its potential advantages. Aloe Vera gel's high viscosity and thermal conductivity could enhance the heat transfer process, thereby maintaining lower PV cell temperatures and improving electrical efficiency [13]. Moreover, Aloe Vera gel is biodegradable, non-toxic, and readily available in many regions, making it an environmentally friendly alternative to conventional fluids. Additionally, the unique composition of Aloe Vera gel might provide added benefits, such as natural antifreeze properties, reducing the risk of freezing in colder climates.

In this research, we will present how the efficiency and performance of PV systems are significantly influenced by the operating temperature of the solar panels. High temperatures can lead to decreased electrical output and reduced lifespan of PV cells. To address this challenge, integrating cooling techniques has become essential for optimizing power generation. This study aims to investigate the potential of using water and Aloe Vera fluid as cooling agents to enhance the thermal management of solar panels. The research focuses on evaluating the thermal performance of PV panels using these two different heat-extracting fluids: water and Aloe Vera fluid. These fluids will be circulated through pipes integrated into the solar panels at a flow rate of 1 LPM. We will conduct a real experimental setup using monocrystalline panels and compare the output power of photovoltaic panels cooled by water and Aloe Vera fluid to determine which is more effective for PVT systems.

2. EXPERIMENTAL SETUP/ METHODOLOYGY

2.1. PVT Module Configuration

In this study, Microsoft Excel was used to perform calculations and graphically display the heat transfer of the PVT module. Figures and diagrams showing the main heat collectors and hypotheses used in the measurements are presented in *figure 1*. The PVT module is mono-crystalline with a maximum power output of 150 W and an electrical efficiency (η_{stc}) of 15.16%. The temperature coefficient of the PVT module (γ) is −0.39%/°C, and other parameters of the PV module are shown in *table 1*. The design for heat absorption from the module utilizes copper pipes of different diameters. The main pipe has a diameter of 12 mm, while the smaller pipes have a diameter of 6 mm. The thickness of all pipes is 0.6 mm. The spacing between the smaller pipes is 60 mm, and they are installed on the backside of the module. The copper sticker sheet used to contact the pipes with the back of the module is 0.1 mm thick and 50 mm wide. Aluminium insulation is installed on the backside of the module after the copper sticker sheet to facilitate heat removal from the module, as illustrated in *figure 1 (a)* and *(b).*



(a)

(b)

Figure 1. (a) Illustrated about design of PVT module; (b) shown about hypotheses of PVT module

The main hypotheses of PVT panel are shown in *table 1*.

Table 1. Features of PVT panel

Cell type	Mono-crystalline
Panel dimensions	1487 mm × 666 mm × 35 mm
Area	0.99 m^2
Weight	12.35 kg
Number of cells	36
Cell dimensions	125 mm ×125 mm
Maximum power, P_m	150 Wp
Maximum power voltage, V_{mp}	18.4 V
Maximum power current, I_{mp}	8.16 A
Open-circuit voltage, V_{oc}	22.7 V
Short-circuit current, I_{sc}	8.58 A
Electrical efficiency of module η_{stc}	15.16 %
Temperature coefficients of P_m, γ	−0.39%/℃

2.2. Aloe Vera Fluid Preparation

To prepare aloe vera fluid, begin by selecting an outer leaf from a fresh aloe vera plant. It is advisable to choose leaves from the base of the plant that exhibit healthy, green stalks, as these are typically more mature and contain more gel. Once selected, rinse the leaf thoroughly under cold water to remove any dirt or debris. After rinsing, trim away any yellow gel that may be present, as it can be bitter and less beneficial. Next, use a vegetable knife or peeler to carefully peel the leaves. This process involves removing the outer layer of the leaf, including the thorns, to expose the clear, mucilaginous gel underneath. It is important to handle the leaf carefully to avoid losing any of the valuable gel. After the gel is exposed, transfer it to a kitchen blender. Blend the gel until it reaches a smooth, consistent texture. The blending process breaks down the gel into a more liquid form, making it easier to filter and use. The final step involves filtering the blended gel to produce a clear aloe vera fluid. This can be done using a fine mesh strainer. Pour the blended gel through the strainer into a clean container, separating the liquid from any remaining solid particles. This preparation process ensures that the aloe vera fluid retains its natural properties and benefits. Each step is crucial for maintaining the integrity and quality of the final product, as illustrated in *figure 2* below. By following these detailed steps, you can efficiently produce high-quality aloe vera fluid from fresh aloe vera leaves.

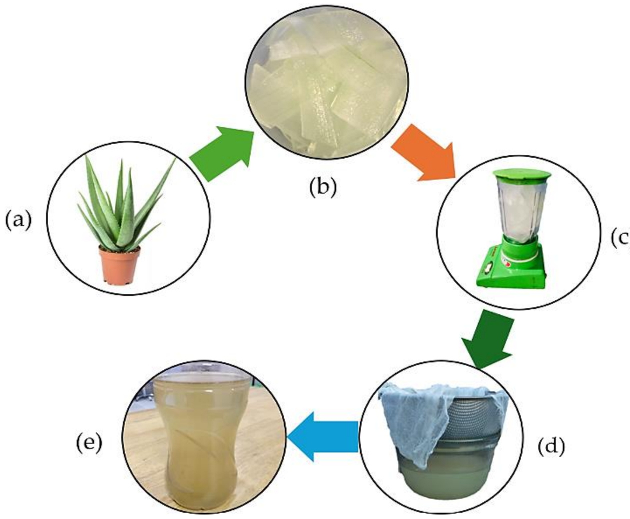


Figure 2. (a) Aloe vera plant; (b) Aloe vera gel; (c) Kitchen blender; (d) Filtering the gel to produce a clear aloe vera fluid; (e) Aloe vera fluid

2.2.1. Aloe Vera Fluid Specific Heat Capacity Testing

Specific heat capacity testing is a method used to measure the amount of heat energy required to raise the temperature of a unit mass of a substance by one degree Celsius (or Kelvin). This property, known as specific heat capacity, varies for different materials and provides crucial insights into how each material responds to thermal energy. To test the specific heat capacity of Aloe Vera fluid, Figure 3 illustrates the setup where a DC power supply is employed to power an electrical heater. This heater heats the water contained in an isolator container, which is cylindrical with dimensions of 20 cm in height and 95 mm in diameter. The testing duration is 5 minutes, timed using a mobile phone timer, with an average current of 1.24A and a voltage of 23.14V applied. The mass of the water, measured at 300g using an MH-series pocket scale, is used to determine the convection heat loss coefficient (h_o) of the isolator container. Temperature measurements are facilitated by Thermocouple Type K. The detail equipment is shown in *table 2*. The convection heat loss coefficient is determined by [14,15]

$$\dot{Q}_{ele} = \dot{Q}_w + \dot{Q}_{loss,w}$$

$$\dot{Q}_{loss,w} = \dot{Q}_{ele} - \dot{Q}_w \tag{1}$$

Where $\dot{Q}_{ele} = VI$ is power of electricity and $\dot{Q}_w = \dot{m}c_{p,w}\Delta T$, is rate of heat absorption.

$$\dot{Q}_{loss,w} = A_o h_o (T_{o,w} - T_\infty) \tag{2}$$

$$h_o = \frac{\dot{Q}_{loss,w}}{A_o(T_{o,w} - T_\infty)} \tag{3}$$

Where $\dot{Q}_{loss,w}$ is rate of heat loss from container. A_o is container outside area. $T_{o,w}$ is temperature on the outside container of water and T_∞ is temperature from 2cm of container. For aloe vera fluid, the same testing process is conducted under the same room condition.

$$\dot{Q}_{ele} = \dot{Q}_{al} + \dot{Q}_{loss,al}$$

So

$$\dot{Q}_{al} = \dot{Q}_{ele} - \dot{Q}_{loss,al} \tag{4}$$

Where $\dot{Q}_{ele} = VI$ is power of electricity and $\dot{Q}_{loss,al} = A_o h_o (T_{o,al} - T_\infty)$.

$$\mathrm{Q}_{al} = \dot{Q}_{al}\Delta t \tag{5}$$

$$\mathrm{Q}_{al} = mc_{al}\Delta T \tag{6}$$

So

$$c_{al} = \frac{\dot{Q}_{al}\Delta t}{m\Delta T} \tag{7}$$

The result from testing water with average ($T_{o,w}$) of 30.43 °C and (T_∞) of 27.56 °C thus, the average convection heat loss coefficient (h_o) is 13.6378 W/$m^2.K$. From this coefficient, let to find $\dot{Q}_{loss,al}$.

So, the heat capacity of aloe vera with average ($T_{o,al}$) of 29.86 °C and (T_∞) 27.57 °C, voltage is 23.27V with current 1.32A, initial and final temperature of aloe vera fluid is 33.95 °C and 40.70°C. Thus, the aloe vera fluid heat capacity is found to be 4236 j/kg.K.

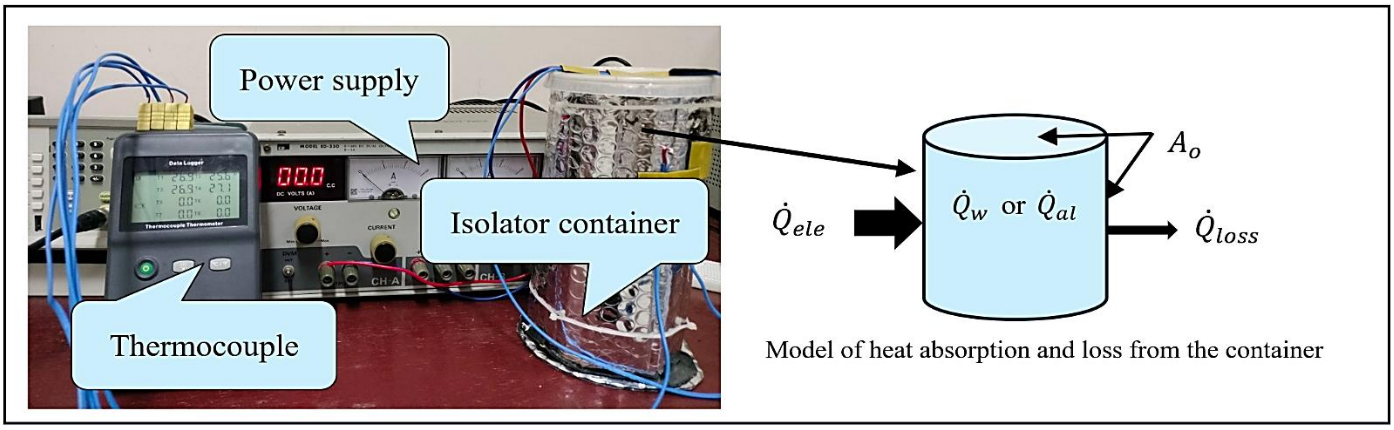


Figure 3. Experimental setup of Aloe Vera Fluid Specific Heat Capacity Testing

2.2.2. Thermal Conductivity of Aloe Vera Fluid

Thermal conductivity is a measure of how much good a material can transfer heat by conduction. It is a property of a substance that depends on its composition and structure. It is measured in units of watts per meter kelvin (W/mK). The thermal conductivity of a material can varies with temperature and can be determined experimentally. The thermal conductivity of water and aloe vera fluid base temperature is shown in *figure 4* [13].

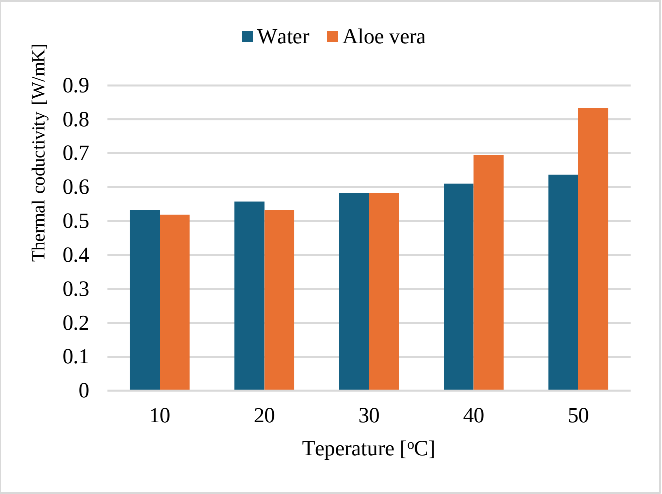


Figure 4. Thermal conductivity of aloe vera fluid is lower than water when temperature lower than $30°C$. But its thermal conductivity is higher than water when its temperature increases higher than $30°C$.

2.3. PVT Experimental System

The PVT experiment is devised it into two parts for researching. The first is model for PVT performance evaluation and second is PVT test rig.

2.3.1 Model for PVT Performance Evaluation

Performance metrics such as the heat absorption rate ($\dot{Q}_{th}$) were calculated using the formula[16].

$$\dot{Q}_{th} = (\dot{m}c_p)_f (T_{fo} - T_{fi}) \quad (8)$$

where ṁ is the mass flow rate of the fluid, c_p is the specific heat capacity of the fluid, T_{fo} is the outlet temperature, and T_{fi} is the inlet temperature. The experiment, conducted under conditions of 800 W/m² solar irradiance and ambient temperatures ranging from 40 to 42°C in clear skies, evaluated the PVT module's performance by determining the rates of heat absorption and heat loss [15,16].

$$\dot{Q}_{th} = F_R(\tau\alpha)_e G_T A - F_R U_L A (T_{fi} - T_a) \quad (9)$$

$$\eta_{th} = \frac{\dot{Q}_{th}}{G_T A} = F_R(\tau\alpha)_e - F_R U_L \frac{(T_{fi} - T_a)}{G_T} \quad (10)$$

The power output of a solar panel depends on the temperature and solar irradiance given to it. To simulation the maximum power of a solar panel, use the following formula[16].

$$P_m = P_{m,stc}(1 - \gamma(T_{PV} - 25)) \frac{G_T}{1000} \quad (11)$$

P_m The maximum power of the solar panel, $P_{m,stc}$ Maximum power of the solar panel in standard test conditions with light density 1000W/m^2 and temperature on PV Module 25 °C. γ is the temperature coefficient that PV can get maximum power. T_{PV} is the temperature on the solar panel.

2.3.2 PVT Test Rig

In this study, the Photovoltaic Thermal (PVT) panel was installed with a 15° south-facing orientation, allowing both water and Aloe Vera fluid to flow inside a copper tube at mass 0.016kg per minute are the same rate of 1 liter per minute (LPM). This setup, illustrated in *figure 5*, involves detailed measurement of the temperatures of the water and Aloe Vera fluid at various points as they flow through the solar panel. The PVT module is designed to convert solar energy into electrical power while also capturing thermal energy for heating purposes. The flow system measures the temperature of the inlet fluid (T_{fi}) entering the system and the outlet fluid (T_{fo}) exiting the PVT module. A micro diaphragm pump, with an 80 W power rating and a maximum flow rate of 5.5 liters per second, was set to 1 LPM for the experiment, consuming only 3 W of electrical power.

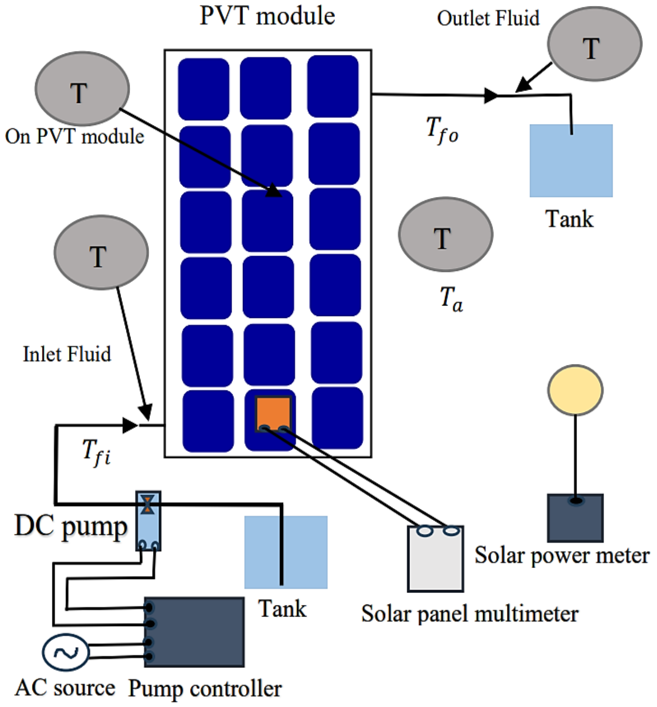


Figure 5. Illustrated installation of the PVT panel and measurement of electrical power and temperature of PVT panel

Temperature measurements include ambient temperature (T_a), module temperature (T_m), and the inlet and outlet temperatures (T_{fi},T_{fo}) to determine the temperature differential as the fluid flows through the PVT panel by thermocouple type K. Solar irradiance (G_T) was measured using a solar power meter. Electrical performance, including maximum power, current, and voltage, was measured using a solar panel multimeter. The detail of equipment for measurement is included in *table 2*.

Table 2. Equipment using for measurement the PVT system

No.	Equipment	Description	Accuracy
1	Solar power meter	Measure solar irradiance, model LX-107	±5%
2	Solar panel multimeter	Measure power, current, and voltage, model EY800W	±1%
3	Thermocouple	Measure temperature, Type K (-200 to +1370°C)	±0.5°C
4	MH-series pocket scale	Measure mass (max.500g)	±1%
5	DC power supply	Supply voltage and current to container, model ED-330	±0.03%

3. RESULT AND DISCUSSION

3.1 Thermal Performance Testing with Aloe vera Fluid and Water

The optical efficiency and heat loss coefficient of the PVT module using water and aloe vera fluid as cooling agents is illustrated in *figure 6*. The optical efficiency (η_{th}) of the PVT module with aloe vera fluid is 52.08%, while the heat loss coefficient is 13.068 W/m²·K. In contrast, the PVT module using water has an optical efficiency of 45.91% and a heat loss coefficient of 10.89 W/m²K. The linear regression equations shown in the figure indicate the relationship between collector efficiency (η_{th}) and the temperature difference normalized by solar irradiance (T_{fi}-T_a)/G_T. For aloe vera fluid, the equation is y=−13.068x+0.5208 with an R^2 value of 0.9553, indicating a strong correlation. For water, the equation is y=−10.89x+0.4591 with an R^2 value of 0.9832, also indicating a strong correlation. These results demonstrate that the PVT module using aloe vera fluid not only achieves higher optical efficiency but also has a higher heat loss coefficient compared to water. This suggests that aloe vera fluid is more effective in absorbing and transferring heat away from the module, which contributes to improved performance.

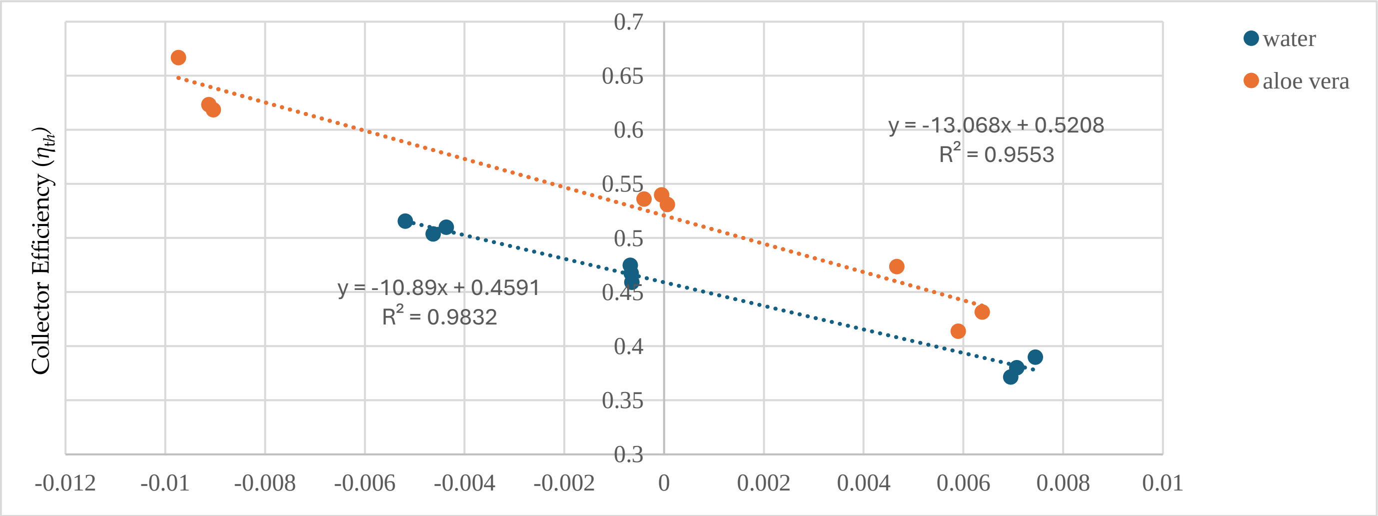


Figure 6. Optical efficiency of PVT module

3.2 Case study of PVT with Aloe Vera Fluid and Water

The testing of PVT on 9th June 2024 with inlet and outlet temperatures of water and aloe vera fluid under the same ambient temperature and solar irradiance ranging from 240 to 847 W/m² is shown in *figure 7*. The outlet temperature of aloe vera fluid is consistently higher than that of water. The average inlet temperatures for water and aloe vera fluid are 36.18°C and 35.77°C, respectively. After flowing through the PVT module, the average temperature increase for water is 5.98°C, while for aloe vera fluid, it is 7.82°C. From the inset graph, it can be observed that the temperature of aloe vera fluid *(*T_{alo}*)* remains higher than the outlet temperature of water *(*T_{wo}*)* throughout the measurement period. The ambient temperature *(*T_{ali}*)* remains relatively stable, showing minor fluctuations. This indicates that aloe vera fluid has a higher heat absorption capacity compared to water, contributing to more efficient cooling of the photovoltaic module. The inset graph provides a detailed view of the temperature variations over a shorter time frame, highlighting the stability of the ambient temperature and the consistent performance of the aloe vera fluid in comparison to water.

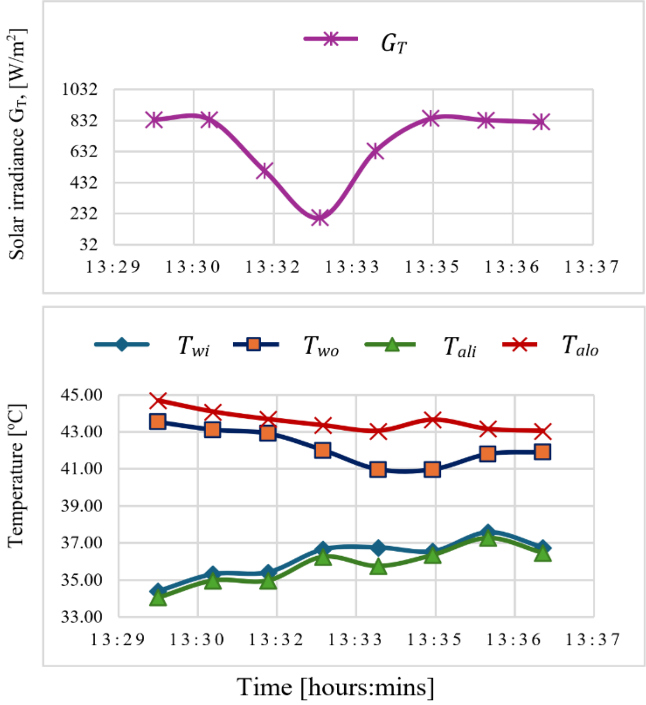


Figure 7. shown about temperature and solar irradiance on PVT module. T_{wi} temperature inlet water, T_{wo} temperature outlet water, T_{ali} temperature inlet aloe vera fluid, T_{alo} temperature outlet aloe vera fluid and G_T solar irradiance.

3.3 Thermal Heat Absorption Rate of PVT with Aloe Vera Fluid and Water

In the case of testing on 9th June 2024, the thermal heat absorption rate of PVT using aloe vera fluid and water are shown in *figure 8*. The rate of heat absorption of aloe vera fluid is higher than 32.41% compared to the water.

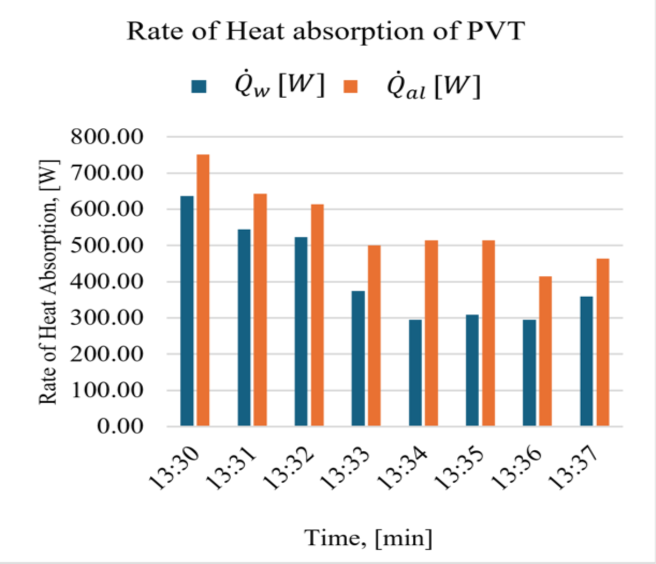


Figure 8. Rate of heat generated by PVT using aloe vera fluid and water absorption

3.4 Electrical Power Generation of PVT

The power generated by the PVT module varies with changes in temperature and irradiance. Using *equation 11* and results from real experiments, *figure 9* illustrates the electrical power generation of the PVT module with water and aloe vera fluid. The comparison includes both simulation and experimental data. The blue curve indicates the solar irradiance over time, the lowest point at around 13:32 to 13:35 on 9th June 2024.

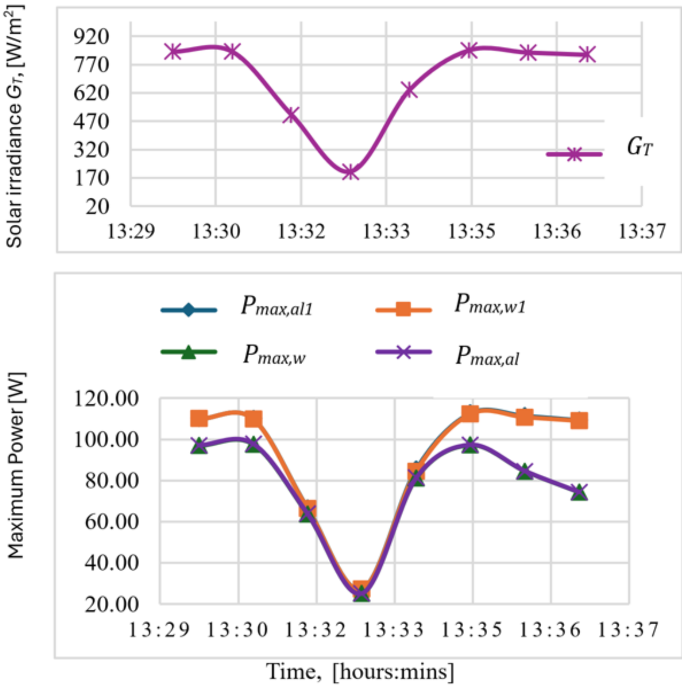


Figure 9. Comparation real experiment and simulation of electrical generated by PVT module. $P_{max,\,al1}$ and $P_{max,\,w1}$ is simulation powered generated by PVT module using aloe vera fluid and water. $P_{max,\,w}$ and $P_{max,\,al}$ is real experiment powered generated by PVT module using aloe vera and water.

The simulation and real experiment show consistent trends, with the lowest power output when the solar irradiance is at the lowest. However, minor discrepancies between simulated and experimental data indicate potential influences of real-world conditions not fully captured in the simulation. Figure 10, this bar chart compares the electrical power generation at specific times (from 13:30 to 13:37) on 9th June 2024 between the two cooling fluids. The average electrical power generated by the PVT module with aloe vera fluid is marginally higher than that with water by approximately 0.21%, demonstrating aloe vera's slight advantage in thermal management. Both *figures 9* and *figure 10* show that aloe vera fluid consistently generates slightly more power compared to water, suggesting better cooling performance and efficiency. The difference is minor (0.21%), but it might be significant in applications where every percentage of efficiency matters.

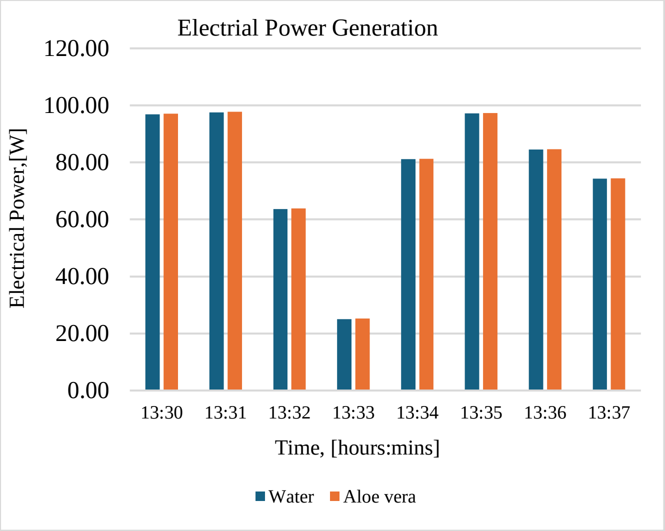


Figure 10. Electric power generated by PVT module using aloe vera fluid and water

3.5 Statistical Analysis

The data collected after the experiment were classified and analyzed using Microsoft Excel and R programming (version 4.3.3) to compare the properties of water and aloe vera fluid. Initially, the data underwent analysis to determine its normalization status by the application of the Shapiro test. The statistical study indicated that the T_{alo} and PVT temperature (T_{mw}), $P_{max,w}$, $P_{max,w1}$, $P_{max,al}$ and $P_{max,al1}$ did not follow a normal distribution. An analysis of normally distributed data was conducted using a T-test to determine the treatment that showed a significant difference. To detect significant differences in non-normally distributed data, the Wilcoxon rank sum test was employed. A p-value over 0.05 at a 95% confidence interval indicates the absence of a statistically significant difference between each treatment combination. *Table 3* displays the p-value obtained from the examined data. The findings indicated that T_{alo} and T_{wo} exhibited statistically significant differences ($p<0.05$), whereas the other data did not show significant differences ($p>0.05$). Thus, according to the statistical study, the aloe vera fluid exhibits superior heat absorption at this temperature compared to water.

Table 3. Data analysis using R programming

Test Rig	T_{wi} vs. T_{ali}	T_{wo} vs. T_{alo}	T_{mw} vs. T_{mal}	$P_{max,w}$ vs. $P_{max,al}$	$P_{max,w1}$ vs. $P_{max,al1}$
p-value	0.4427	0.003561	0.1559	0.7209	0.7209

4. CONCLUSION

The optical efficiency and heat loss of the PVT module using aloe vera fluid are higher than those using water by 6.17%, with the heat loss coefficient being 2.17 W/m²·K greater. The average thermal efficiency of the PVT module with aloe vera fluid is 80.62%, and its electrical efficiency is 11.34%. In comparison, the average thermal efficiency of the PVT module with water is 60.78%, and its electrical efficiency is 11.32%. The heat capacity of the aloe vera fluid, determined from the average convection heat loss coefficient of 13.6378 W/m²·K, is 4236 J/kg·K. Compared to water, the thermal heat rate of aloe vera fluid absorption from PVT is 32.41% higher. Additionally, the effective reduction of the module temperature leads to a 0.21% increase in electrical power production compared to the use of water. Furthermore, according to the statistical study, the use of aloe vera fluid enhances heat absorption at this temperature more effectively than the use of water. This study focused on the optical efficiency of PVT modules using water and aloe vera media in a specific configuration. However, limitations include a small sample size and insufficient exploration of external factors like environmental conditions and material variations. Future research will address these issues by testing a broader range of PVT module configurations under various climatic conditions. This will enhance the understanding of PVT module performance and account for external factors affecting optical efficiency.

ACKNOWLEDGEMENTS

This research was funded by the National Polytechnic Institute of Cambodia. Special thanks are extended to Dr. Vat Sun for consistently providing measurement equipment and offering valuable insights for carrying out the measurements.

REFERENCES

[1] Al-Odat, M. Experimental Study of Temperature Influence on the Performance of PV/T Cell under Jordan Climate Conditions. J. Ecol. Eng. 2022, 23, 80–88, doi:10.12911/22998993/152283.

[2] Miglioli, A.; Aste, N.; Del Pero, C.; Leonforte, F. Photovoltaic-Thermal Solar-Assisted Heat Pump Systems for Building Applications: Integration and Design Methods. Energy and Built Environment 2023, 4, 39–56, doi:10.1016/j.enbenv.2021.07.002.

[3] Tirupati Rao, V.; Raja Sekhar, Y. Hybrid Photovoltaic/Thermal (PVT) Collector Systems with Different Absorber Configurations for Thermal Management – A Review. Energy & Environment 2023, 34, 690–735, doi:10.1177/0958305X211065575.

[4] Ma, Y.; Xi, J.; Cai, J.; Gu, Z. The Optimization and Energy Efficiency Analysis of a Multi-Tank Solar-Assisted Air Source Heat Pump Water Heating System. Thermal Science and Engineering Progress 2024, 48, 102387, doi:10.1016/j.tsep.2024.102387.

[5] Lilley, D.; Yu, P.; Ma, J.; Jain, A.; Prasher, R. Thermal Fluids with High Specific Heat Capacity through Reversible Diels-Alder Reactions. iScience 2022, 25, 103540, doi:10.1016/j.isci.2021.103540.

[6] Prakash, J. Transient Analysis of a Photovoltaic-Thermal Solar Collector for Co-Generation of Electricity and Hot Air/Water. Energy Conversion and Management 1994, 35, 967–972, doi:10.1016/0196-8904(94)90027-2.

[7] Pei, G.; Zhang, T.; Yu, Z.; Fu, H.; Ji, J. Comparative Study of a Novel Heat Pipe Photovoltaic/Thermal Collector and a Water Thermosiphon Photovoltaic/Thermal Collector. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 2011, 225, 271–278, doi:10.1177/2041296710394271.

[8] Abdel-Mesih, B.S.A.; Abdelrehim, A.A.; Khobeiz, A.M.H. Comparative Analysis Between Water and Nanofluids as Working Fluids in Photovoltaic Thermal Collectors. In Proceedings of the Volume 6B: Energy; American Society of Mechanical Engineers: Montreal, Quebec, Canada, November 14 2014; p. V06BT07A034.

[9] Hazi, A.; Hazi, G. Comparative Study of Indirect Photovoltaic Thermal Solar-Assisted Heat Pump Systems for Industrial Applications. Applied Thermal Engineering 2014, 70, 90–99, doi:10.1016/j.applthermaleng.2014.04.051.

[10] Rahbar, K.; Riasi, A.; Khatam Bolouri Sangjoeei, H.; Razmjoo, N. Heat Recovery of Nano-Fluid Based Concentrating Photovoltaic Thermal (CPV/T) Collector with Organic Rankine Cycle. Energy Conversion and Management 2019, 179, 373–396, doi:10.1016/j.enconman.2018.10.066.

[11] Hussain, M.I.; Kim, J.-H.; Kim, J.-T. Nanofluid-Powered Dual-Fluid Photovoltaic/Thermal (PV/T) System: Comparative Numerical Study. Energies 2019, 12, 775, doi:10.3390/en12050775.

[12] Mansoor, H.H.A.; Devarapu, S.R.; Samuel, R.; Sharma, T.; Ponmani, S. Experimental Investigation of Aloe-Vera-Based CuO Nanofluid as a Novel Additive in Improving the Rheological and Filtration Properties of Water-Based Drilling Fluid. SPE Drilling & Completion 2021, 36, 542–551, doi:10.2118/205004-PA.

[13] Sathishkumar, A.; Sundaram, P.; Ranga, S.P.; Kumar, P.G.; Cheralathan, M.; Velraj, R. Role of Aloe Vera Based Nanofluids for Cool Thermal Energy Storage System: A Comparative Study. Journal of Energy Storage 2024, 90, 111710, doi:10.1016/j.est.2024.111710.

[14] Duffie, J.A.; Beckman, W.A.; Blair, N. Solar Engineering of Thermal Processes: Photovoltaics and Wind; Fifth edition.; John Wiley & Sons, Inc: Hoboken, New Jersey, 2020; ISBN 978-1-119-54028-1.

[15] Kong, R.; Deethayat, T.; Asanakham, A.; Kiatsiriroat, T. Performance and Economic Evaluation of a Photovoltaic/Thermal (PV/T)-Cascade Heat Pump for Combined Cooling, Heat and Power in Tropical Climate Area. Journal of Energy Storage 2020, 30, 101507, doi:10.1016/j.est.2020.101507.

[16] Sun, V.; Asanakham, A.; Deethayat, T.; Kiatsiriroat, T. Evaluation of Nominal Operating Cell Temperature (NOCT) of Glazed Photovoltaic Thermal Module. Case Studies in Thermal Engineering 2021, 28, 101361, doi:10.1016/j.csite.2021.101361.