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Examining Various Finned Collector Geometries in the Water/Al_2O_3 Based PV/T System: An Analysis Using Computational Fluid Dynamics Simulation

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ABSTRACT

Nanofluid-based finned collector designs have been explored to enhance solar spectrum utilization and thermal efficiency in photovoltaic-thermal (PV/T) systems. Combining nanofluids with finned collector designs improves heat transfer processes. Over the past five decades, various research methods have been used to analyze system performance, including experimental studies, theoretical analysis, design modification, advanced technologies, and soft computing techniques. This research examines the impact of fin geometry on energy conversion of Water/Al_2O_3-based PV/T systems using 3D CFD modeling simulations using ANSYS Fluent and ANSYS Steady State Thermal software. This study found that the quadrilateral fin geometry produced the lowest PV temperatures, followed by each concentration's pentagon and triangle fin geometries. The PV temperature decreased as the electrical efficiency increased, with the quadrilateral fin geometry with 1% Water/Al_2O_3 fluid producing the highest efficiency of 12.83%. The amount of PV heat absorbed by the working fluid affects the output temperature, which causes thermal energy conversion to be inversely proportional to electrical efficiency. Pentagon fin geometry with 4% Water/Al_2O_3 fluid produces the highest thermal conversion of 22.28%. In addition, this study also found significant differences in results for the three fin geometries on the collector, but no significant differences for the six Water/Al_2O_3 working fluids studied.

1. INTRODUCTION

Photovoltaic/thermal collector (PV/T) is a power generation technology that converts solar radiation into heat and electrical energy. This technology combines photovoltaic solar cells with a thermal collector, transferring waste heat to a heat transfer fluid. This technology achieves higher efficiency than PV or thermal collectors alone [1]. Factors influencing PV/T system performance include collector design, fluid flow rate, solar radiation, temperature, tilt angle, and heat pump system. Optimization aims to find the best combination of variables for maximum performance [2, 3]. Strategies for improving PV/T systems include flow channel layout, collector design, collector material, and cooling fluid type.

In summary, integrating photovoltaic cells with thermal collectors, careful design choices, and exploring nanofluid variables contribute to efficient energy conversion [4]. By continuing to refine these approaches, research can contribute to the sustainable and effective use of solar energy. Research methods include experimental studies, theoretical analysis, design modification and development, use of advanced technology, and soft computing techniques. Experimental studies have been conducted on various PV/T systems over the past five decades, with comprehensive mathematical models developed to analyze heat transfer processes and operational efficiency. Simulation and numerical modeling have been widely used to analyze system performance, with comprehensive mathematical models developed to investigate heat transfer processes and operational efficiency. Soft computing techniques play a role in predicting the impact of various parameters on photovoltaic-thermal systems [5, 6].

Collector designs, such as round and quadrilateral shapes, with commonly used materials such as copper and aluminum. Fins can improve electrical and thermal efficiency by increasing the surface area available for heat exchange. Temperature considerations are critical for optimal performance, as photovoltaic module efficiency is affected by external temperature and operating cell temperature. Research on finned collector designs in PV/T systems has shown significant improvements in performance and temperature. Different fin shapes and arrangements can improve heat transfer, increasing system efficiency [7]. Another study aims to simulate the thermal performance of finned PV/T solar collectors using computational fluid dynamics methods, using fins and air as working fluids. The results showed that a 50 mm fin height caused a 7.04% reduction in the average PV/T surface temperature, while a 37.5 mm fin height resulted in an 11.9% reduction [8, 9].

Nanofluid-based finned collector designs have also been explored, with nanofluid-based optical filters and zinc oxide nanofluids used to improve solar spectrum utilization. A study using a nanoparticle-loaded BSPV/T system showed significant improvements in thermal efficiency [10-12]. Additionally, integrating collectors with fins has improved performance by increasing electrical and thermal efficiency. Combining nanofluid and finned collector designs is essential to increase the efficiency of PV/T systems, using different fin shapes and arrangements to improve the heat transfer process [13].

Variable nanofluids, consisting of nanoparticles dispersed in a base fluid, offer exciting possibilities for PV/T systems. Al_2O_3 nanofluid has been shown to have higher overall efficiency than water in flowing PV/T systems. Metal oxide-based nanofluids, such as Al_2O_3-water nanofluids, TiO_2-water nanofluids, and SiO_2-water nanofluids, have demonstrated high heat transfer and thermal efficiency features [14-16]. However, further research is needed to address existing challenges and limitations. Additionally, advances in nanofluid-based fluid flow rate research have demonstrated significant improvements in PV/T systems. The optimum flow rate and nanoparticle concentration have been determined to be 0.15% and 12 LPM, respectively. Al_2O_3 nanofluid as a flowing fluid for square pipes has been proven to increase the fluid outlet temperature and reduce the surface temperature of solar panels. The heat transfer coefficient and Nusselt number of nanofluids are higher than those of base fluids and increase with increasing Reynolds number and flow rate [17].

Based on the background, further investigation should be into simulation studies of PV/T systems with finned collectors. Therefore, this research was conducted as the first step before further experimental stages. Comparative modeling analysis was performed for various fin geometry variations, which include pentagon, quadrilateral, and triangle with a nano-fluid liquid concentration of water/Al_2O_3 (0-4%), with a nano-fluid flow rate of 0.5 liters per minute. Research with simulation studies benefits from the time and cost savings required.

2. ADVANCES IN THE STUDY OF FINNED COLLECTORS IN NANOFLUID-BASED PHOTOVOLTAIC/THERMAL SYSTEMS

The energy conversion efficiency of nanofluid-based photovoltaic/thermal systems with finned and non-finned collectors has increased with encouraging results, as shown in Table 1. Research has looked at nanofluids such as silver, copper, iron, Fe, Al_2O_3, TiO_2, and CuO dissolved in water or other alkaline fluids to increase thermal and electrical output [18]. Compared to pure fluids, adding nanoparticles to nanofluids has increased thermal and electrical power; the best results were obtained at specific volume fractions and mass flow rates. Furthermore, the impact of various nanofluids, including Al_2O_3/water and Cu/water, on improving the performance of PV/T systems has been studied, showing enhancements in electrical and thermal efficiency compared to pure water-based systems [19]. It has been demonstrated that using nanofluids as coolants in photovoltaic-thermal systems can lower panel temperature, increase efficiency, and improve heat transfer performance. The design of the collector fins dramatically affects the performance of nano-fluid-based photovoltaic/thermal systems.

Table 1. Advances in the study of finned collectors in nanofluid-based

Ref.	Design of Fins	Working Fluid	Results	Findings
[7]	• Micro-fin tube design: 1.74 mm fin pitch, 0.153 mm in height, 24-degree fin helix angle, 9.52 mm pipe inner diameter, 75-degree fin angle.	• 0.6, 0.3 vol% nanofluid • Nano PCM containing 1% SiC nanoparticles.	• 10.8% electrical efficiency. • 83.3% thermal efficacy with enhanced heat transfer. • Micro-fin tubes and twisted tape significantly improved thermal properties.	PVT System Experiment Findings • Micro-fin tube and twisted tape with nano PCM and nanofluid circulation achieved maximum thermal efficiency of 83.3%. • Micro-fins and twisted tape significantly improved heat transfer properties, enhancing thermal performance. • Nanofluids and nano-PCM systems showed the highest thermal efficiency, thermal energy, and electrical exergy.
[20]	• Utilizes finned-tube collectors and MWCNT-PCM layer.	Research on Operating Fluid Characterization • Utilizes uniform, incompressible, fully developed operating fluid in the collector. • Characterized by dynamic viscosity, fluid velocity, pressure, and density. • Considers fluid temperature and heat capacity at a fixed pressure.	• Increases thermal content in temperature profiles. • Validation study confirms numerical modeling accuracy.	• Application of fins in working fluid-based collectors enhances system performance. • The nanoparticle-based phase change material (PCM) layer and finned collectors improve electrical efficiency. • Maximum thermal efficiency values achieved at wind speeds less than two m/s and direct normal irradiance higher than 950 W/m^2. • Optimal conditions include optimal melted PCM, coolant outlet temperature, and electrical efficiency values.
[13]	• Advises PVT-8S system for optimal performance.	Research Fluid: Nanofluid of Water/Magnetite • Prepared via co-precipitation method.	PVT-8S System Performance • Highest energy, exergy, and electrical efficiency. • Fins slightly enhance electrical power.	• PVT-8S system showed highest overall energy efficiency compared to PVT-4S and PVT-0S systems. • PVT-8S system demonstrated maximum exergy efficiency. • Adding cooling systems to PV panels increased electrical efficiency, with the PVT-8S system showing the highest increase.

				• Temperature difference between PV module and PVT systems increased with flow rate and nano concentration enhancement. • The addition of fins in collectors gradually increased the temperature difference, with the PVT-0S system having the lowest and the PVT-8S system showing the maximum difference.
[21]	• Modification with rifled serpentine tubes.	Research Uses Water/Magnetite Nanofluid • Conducts experiments.	6-Star Rifle PVT System Performance • Achieved 22.5% higher energy efficiency. • Generated 31.5% more electrical power. • Compared base, 3-start, 6-start PVT systems.	• 6-start rifled PVT system outperformed base and 3-start rifled systems. • Base, 3-start, and 6-start rifled PVT systems significantly enhanced electrical power compared to PV modules without cooling. • The 6-start rifled system showed the highest enhancement in electrical power generation.
[22]	• 8-lobed HTT and circular HTT	Research on Heat Transfer Fluid • Utilizes non-toxic graphene nanoplatelets (GNP) mixed with water. • Uses nanofluid as working fluid. • Nano-sized powders dispersed in base fluid for high thermal conductivity.	PVT Unit Design Update • Improved tube geometry. • Analyzed thermal uniformity, fluid properties, and system performance.	• Copper fins are placed around the heat transfer tube (HTT) for the highest efficiency. • Non-toxic graphene nanoplatelets mixed with water in HTF improve electrical performance by 5.8%. • Improved exergy, electrical, and thermal performances. • System reduces carbon dioxide emissions by 7.1 tons, with a 5.5% higher carbon credit than the base case. • The payback period is less than two years, with a profit of $18700 in the 10th year.
[23]	• Micro-fin tube used with fin pitch, height, helix angle, inner diameter, and angle.	• Water and nanofluid with 0.6 vol% SiC used. • Nano PCM contains 1% SiC nanoparticles. • Improves electrical, thermal, and photovoltaic thermal efficiencies.	PVT System Efficiency • 9.6% electrical efficiency • 77.5% thermal efficiency • Nanoofluid SiC and Nano-PCM were used	• Found system had 9.6% electrical efficiency and 77.5% thermal efficiency in PVT M.F.N.F.N.PCM configuration. • Nanofluid and PCM in cooling systems increased system exergy efficiency by over 23% compared to standard PV modules.

The shape of nano-fluid fins significantly impacts the heat transmission and circulation properties. Mini-channels with trapezoidal, square, sinusoidal, and triangular fins reduced the thermal inability by 66.23%, 61.87%, 59.21%, and 57.80% compared to smooth channels [24]. Bilateral triangular fins affect circular ducts' heat transfer rate and flow pattern. New fin shapes such as Tree, T, and H affect heat transmission in porous layers and cavities containing nanofluids [25]. Spherical nanoparticles require less pumping power in forced convection, while blade-shaped or cylindrical nanoparticles perform well in heat transmission. Rhombic pin fins perform better heat dissipation than circular fins. Half-round fins and angled fin arrays improve heat transmission performance. Fins also enhance the performance of solar photovoltaic cells in nano-fluid-based collectors, increasing electrical and thermal efficiency [26, 27]. Combining fins and nanofluid stabilizes and improves thermal efficiency in PVT systems. Therefore, the geometry design of the fins in the collector is essential for studying nanofluid-based PV/T systems.

3. METHODS

The research carried out a Computational Fluid Dynamics (CFD) investigation of the performance of a nanofluid-based PV/T system modifying the geometry of pentagon, quadrilateral, and pentagon-shaped fins. A geometric shape can influence the collector's heat transfer surface and flow patterns. The influence of geometry is also reviewed with the working fluid used. The working fluid uses a Water/Al_2O_3 nanofluid with a 0 - 4% concentration and a fluid flow rate of 0.5 liters/minute. The collector design was carried out with mesh independence, and then a CFD investigation was carried out to determine the PV temperature and fluid output. Next, an analysis of the electrical energy conversion of PV solar cells is carried out. The research flow can be seen in Figure 1.

3.1 Modeling design

The material for this research is a photovoltaic solar cell module measuring 660×540×4.33 mm with a temperature coefficient of -0.4%/K [28]. The geometric model design was created with Solidworks software. Figure 2 and Table 2 show the PV design structure using a finned collector. The finned collector design is a direct flow model, as in Figure 3, while the form of the flow input is as in Figure 4. The input dimensions of the collector are 274 mm^2. The collector design was changed based on the fin shape in this study. Three different fin geometric shapes are reviewed: pentagon, quadrilateral, and pentagon. There is uniformity in the area of geometric shapes. In the simulation, the pipe has a thickness of 1.5 mm, and the collector is made of aluminum.

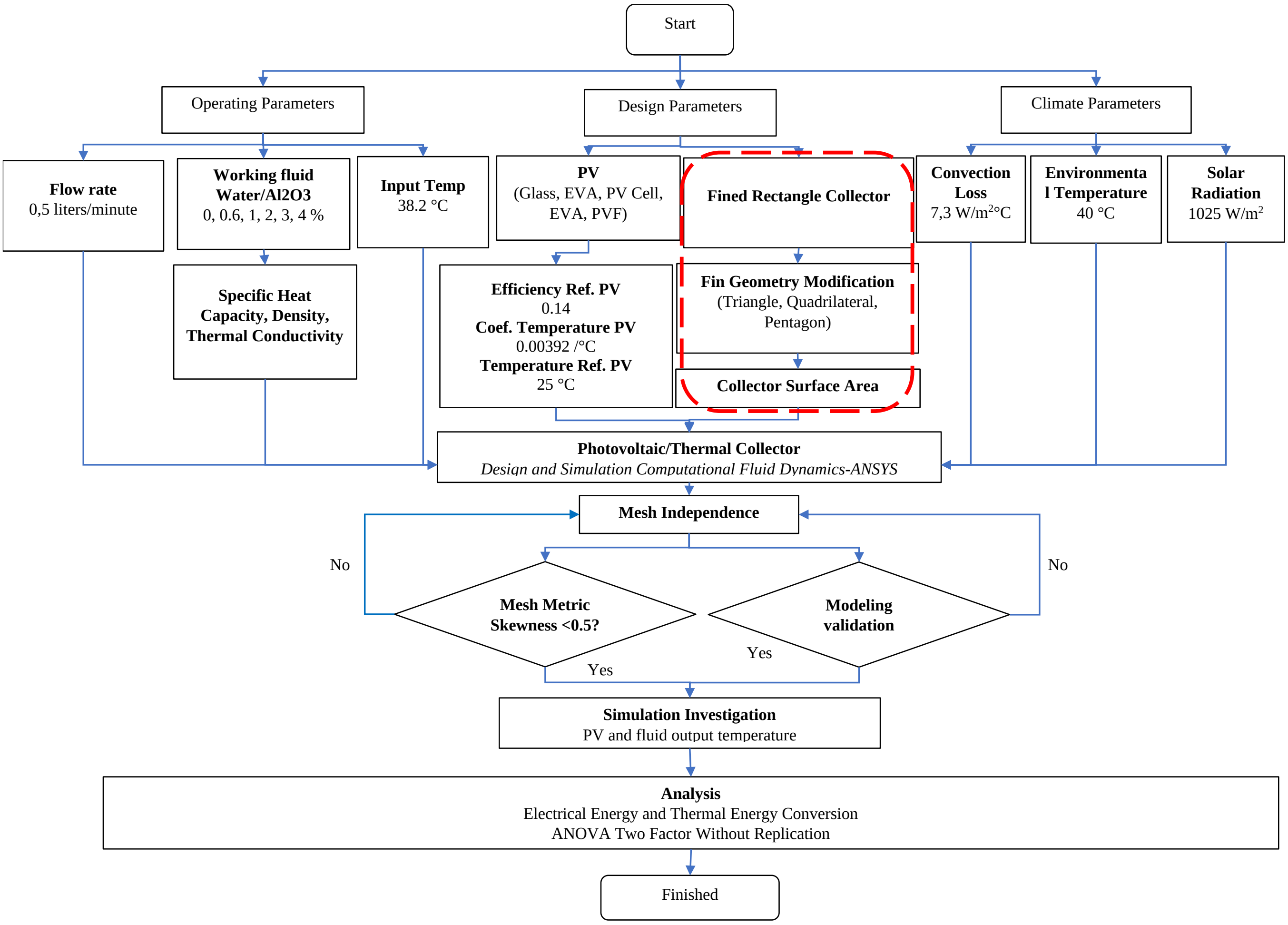


Figure 1. Research flow diagram

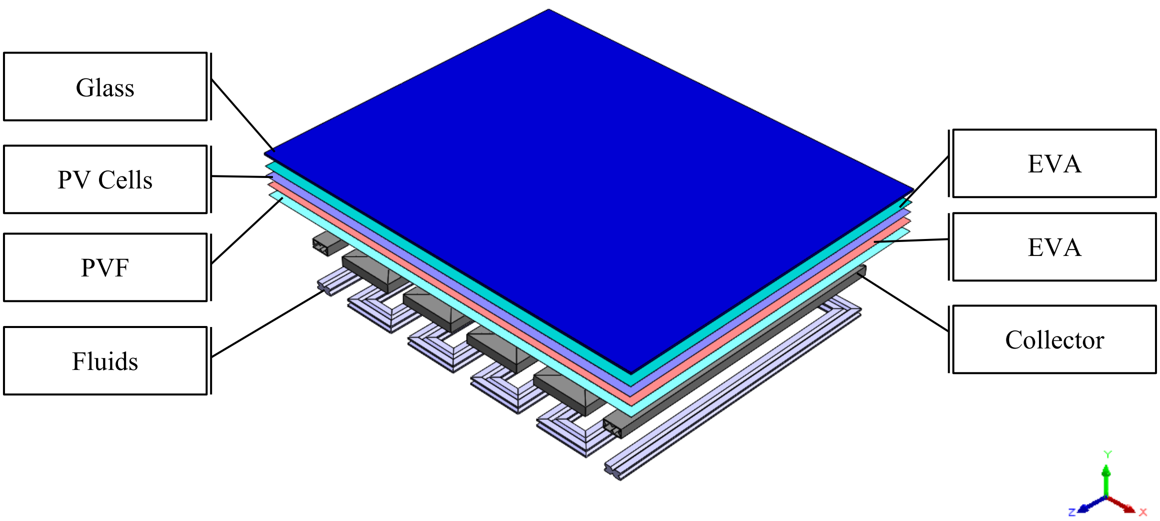


Figure 2. PV/T system structure

Table 2. Specifications of layers in PV cells [29, 30]

Layers	Density (kg/m^3)	Specific Heat Capacity (J/kgK)	Thermal Conductivity (W/mK)	Thickness (mm)
Glass	2450	790	0.7	3.2
EVA	960	2090	0.311	0.5
PV cells	2330	677	130	0.21
EVA	960	2090	0.311	0.5
PVF	1200	1250	0.15	0.3
Collector	900	2700	160	1.5

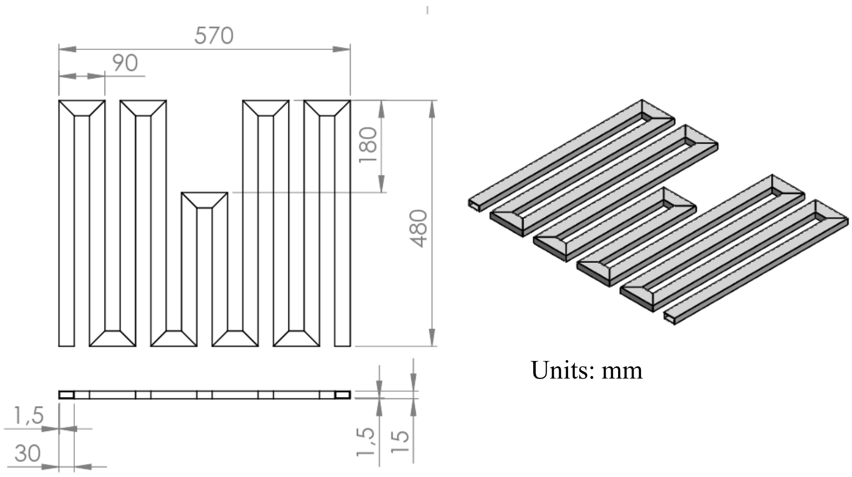


Figure 3. Finned collector design

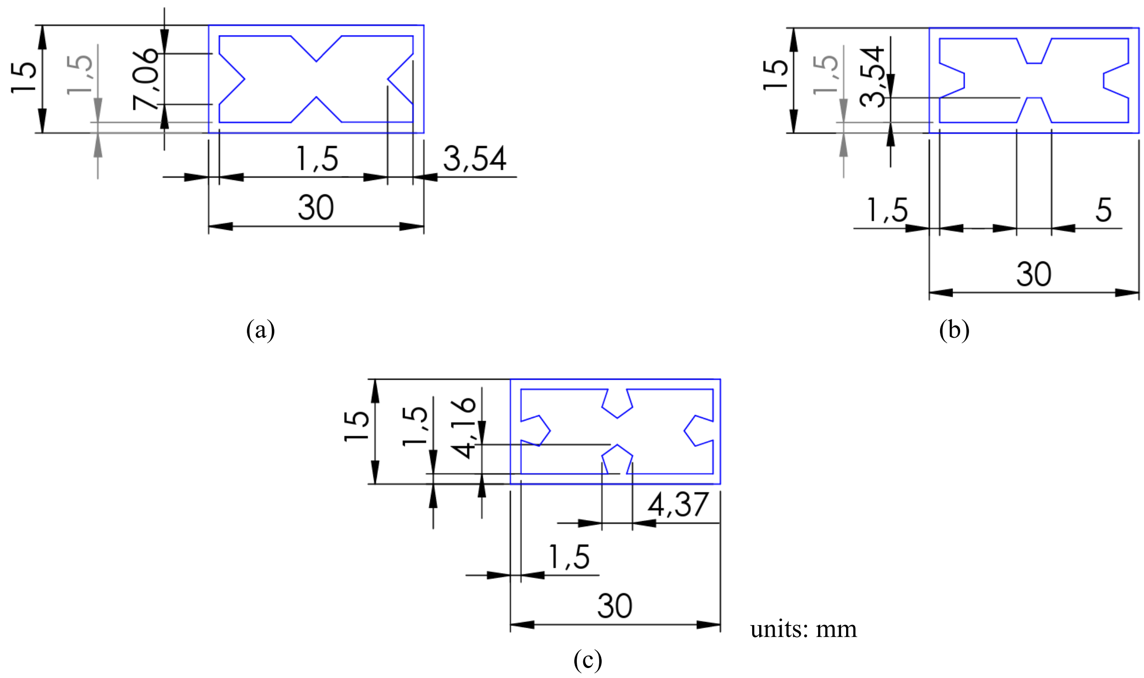


Figure 4. Design of a finned collector with geometric shapes (a) triangle (b) quadrilateral (c) pentagon

Table 3. Characteristics of water/Al_2O_3 nanofluids [31, 32]

Property	φ=0%	φ=0.6%	φ=1%	φ=2%	φ=3%	φ=4%
Density (kg/m^3)	998.2	1013.81	1024.2	1050.2	1076.3	1102.3
Specific heat (J/kgK)	4182	4109.2	4061.9	3947.7	3839.1	3735.6
Thermal conductivity (W/mK)	0.613	0.624	0.686	0.767	0.843	0.914
Viscosity (Ns/m^2)	0.001002	0.00104	0.00113	0.00131	0.00155	0.00192

Water/Al_2O_3 is a cooling medium for PV/T systems. The type of Al_2O_3 nanoparticles was selected after considering the thermophysical characteristics. As a heat-conducting fluid, this type of nanofluid is often used [33]. This research will test different nanofluid volume fractions to maximize the efficiency of solar photovoltaic panels. The total volume fractions of nanofluids are 0, 0.6, 1, 2, 3, 4% volume. The characteristics of Al_2O_3 nanofluid are reviewed in Table 3.

3.2 Modeling simulation

The research modeling of PV solar cells is influenced by solar radiation and convection losses, with fluid flowing from the inlet to the outlet, as in Figure 5. This results in a decrease in temperature and an increase in PV efficiency. Assumptions for this study include a perfectly isolated collector, negligible PV radiation losses, no energy generation, steady-state fluid flow, uniform water flow, constant ambient temperature, and constant thermophysical parameters of each solid layer. Generated in the simulation, the PV solar cell efficiency value for each variation is determined. Factors that influence heat transfer include thermal properties of fluid heat transfer, kinematic properties of fluid heat transfer, collector flow design, collector surface area, collector contact type with PV cells, and flow type (turbulent). Study on System Modeling Simulation and Mesh Quality as follows.

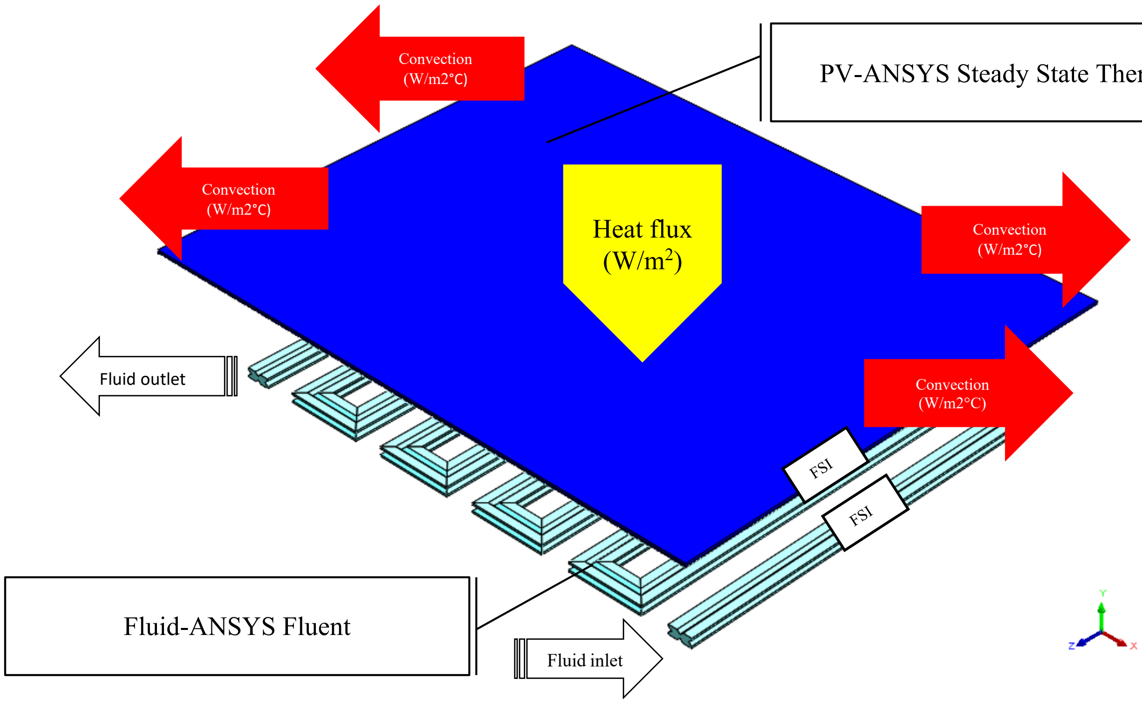


Figure 5. PV/T system modeling scheme

3.2.1 Boundary conditions

(1) Fluid flow studies using ANSYS FLUENT software for steady state simulation with the k-ε Re-Normalization Group (RNG) turbulence model.

(2) The input fluid mass flow rate was varied with a temperature of 38.2°C, turbulence intensity of 5%, and hydraulic diameter of 0.128 m.

(3) The solution method used is COUPLED Green Gauss cell-based.

(4) The established convergence criteria are 10E-6 for energy and 10E-4 for pressure, velocity, and continuity equations.

(5) Thermal study on PV using ANSYS Steady State Thermal software.

(6) Solar radiation of 1025 W/m^2 is modeled with the heat flux module (Q). Natural convection (h) is 7.3 W/m^2°C.

(7) The boundary condition is expressed as the only top surface of the PV cell exposed to the heat flux.

(8) The boundary conditions under which a PV cell or collector has contact with air are defined according to the properties of the materials that make up the PV cell.

(9) The following is the differential equation that governs heat transmission and fluid flow:

Conservation of mass (the continuity equation):

$$\nabla\vec{V} = 0 \tag{1}$$

Conservation of momentum (Navier-Stokes equation):

$$(\nabla\vec{V})\vec{V} = -\nabla p + \mu\nabla^2\vec{V} \tag{2}$$

Conservation of energy for solid (3D Heat conduction equation):

$$\nabla(k_w \nabla T_w) = 0 \tag{3}$$

The variables k_w, T_w, p, $\vec{V}$ and μ represent thermal conductivity, temperature, and pressure in Pascal, velocity vector (m/s), and dynamic viscosity (Kg/sec), respectively.

3.2.2 Meshing

(1) The simulation's accuracy depends on the mesh skewness quality.

(2) The mesh quality is set in this simulation by default with a mesh size of 25 mm to ensure the computer can run the simulation and provide reasonably accurate results.

(3) The mesh independence test is carried out to obtain the most appropriate mesh size for a PV/T system with the highest electrical efficiency.

3.2.3 Post-processing

(1) The simulation data shows the PV cells' average temperature and the collector outlet flowing through the channel.

(2) The temperature results are analyzed to determine electrical and thermal efficiency.

3.3 Energy analysis

The value of the electrical energy efficiency of photovoltaic (PV) cells is inversely proportional to the significant increase in cell operating temperature during the absorption of solar radiation. Electrical energy efficiency (ηel), expressed as Eq. (4):

$$\eta_{el} = \eta_{ref}[1 - \beta_{ref}(T_c - T_{ref})] \tag{4}$$

where, η_{ref} represents the PV solar cell reference efficiency, βref represents the PV solar cell temperature coefficient, and Tref represents the PV initial reference temperature. When Tref is 25°C, then ηref and βref are 0.14 and 0.00392 /°C for silicon-based PV solar cells. CFD simulation is used to obtain the final average temperature of PV to calculate the amount of ηel utilizing this equation. Meanwhile, thermal energy efficiency (ηth) can be found using the Eq. (5):

$$\eta_{th} = \frac{mc_p(T_o - T_i)}{IA} \tag{5}$$

where, m is the mass flow rate, cp is the specific heat capacity of the heat transfer fluid, To is the output temperature produced in the CFD simulation of the fluid. Ti is the initial temperature of the fluid entered into the collector. I represent the intensity value of solar radiation, and A is the cross-sectional area of the collector [34].

4. MODELING SYSTEM VALIDATION

The computational fluid dynamics simulation modeling system was validated by comparing the results of laboratory-scale experiments [35, 36]. Simulations were carried out to estimate the average PV temperature and working fluid output. Experimental studies were carried out by referring to previous research in the laboratory. The experimental study process was carried out in Surakarta, Indonesia. The distinguishing parameters are 0.6% Water/Al_2O_3 working fluid, and the collector shape is a finned collector with a pentagon geometry. Next, several input parameters required in the simulation are equated with the actual conditions in the experiment. Input parameters include radiation intensity (550-1025 W/m^2), environmental temperature (40℃), fluid flow rate (0.5 liters per minute), fluid inlet temperature (38.2℃), and working fluid characteristics (Water/Al_2O_3 0.6%). The validation process was completed by comparing the PV temperature results in simulation and experimental studies. The fluid dynamics computational simulation modeling system carried out in the research is valid if the mean average percentage error (MAPE) value is less than 10%, so the simulation study is suitable for other variations of research on PV/T systems.

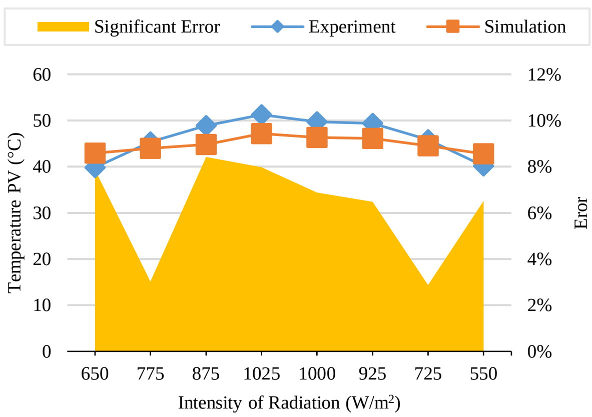


Figure 6. Validation of the modeling simulation system

Figure 6 shows the PV temperature results in experimental and simulation studies from 8 to 15 o'clock with the resulting radiation intensity of 550-1025 W/m^2. Based on the trend of PV temperature results produced using simulation studies, the results are lower than those of experimental studies. The highest PV temperature value was created at a radiation intensity of 1025 W/m^2 of 51.24℃ for the experimental research and 48.04℃ for the simulation study. So, using a radiation intensity of 1025 W/m^2 is promising when using the developed finned collector. Apart from that, the resulting error value is 2.9-8.4% for each radiation intensity. This indicates that there are differences in results for each study produced. However, based on the MAPE value of 6.3%, it classifies that the simulation study has prediction results with high accuracy. This is because the MAPE value is less than 10% so the simulation modeling system can be used in research [37].

The basic validation of the CFD study was carried out using experimental studies on a laboratory scale. Validation on the fins in the triangular collector of the Al_2O_3 nanofluid-based PV/T system. The experimental study was conducted as in previous studies [35, 36], with the CFD study parameters and experiments being equalized. The most significant error value was generated at 8%, and the slightest error was generated at 4%, as shown in Figure 7. The MAPE generated for the whole system was 6%, which indicates a high accuracy of agreement between the results of the 3D CFD study and the experimental study.

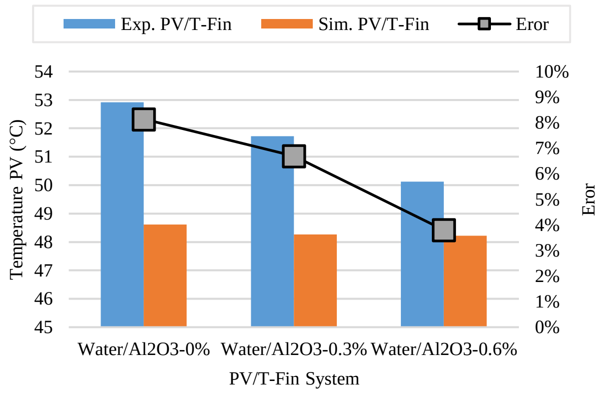


Figure 7. Validation of CFD study based on experimental study

5. RESULTS AND ANALYSIS

The analysis is based on simulation modeling data for each fin geometry variation (triangle, quadrilateral, pentagon) in a PV/T system based on Water/Al_2O_3 (Concentration 0, 0.6, 1, 2, 3, 4%). The modeling simulation used a 3D CFD approach using ANSYS Fluent software coupled with ANSYS Steady State Thermal. The simulation results include PV temperature data and output fluid. Next, it was analyzed based on electrical and thermal efficiency calculations using Two Way ANOVA Without Replication. The analysis is intended to determine the effect of fin geometry in the collector in a Water/Al_2O_3-based PV/T system on the resulting energy conversion.

5.1 PV/T system temperature analysis

This section is devoted to broadening the perspective on the influence of fin geometry in the collector in a Water/Al_2O_3-based PV/T system on PV temperature and output fluid. Three types of fin geometry (triangle, quadrilateral, pentagon) and five types of Water/Al_2O_3 concentrations (0, 0.6, 1, 2, 3, 4%) are used to analyze the system temperature and evaluate the cooling effect on PV solar cells. The heat transfer process also supports this through natural convection in PV. It can be seen that the use of quadrilateral fin geometry in a collector with a 1% concentration of Water/Al_2O_3 fluid produces a minimum

PV temperature of 46.37°C. In comparison, the maximum PV temperature is found using a pentagon fin geometry in a collector with a 4% concentration of Water/Al_2O_3 fluid of 50. 07°C, as in Figure 8.

As in the trend graph, quadrilateral fin geometry in the collector produces the lowest temperature, followed by pentagon and pentagonal fin geometry for each fluid concentration of Water/Al_2O_3. The difference in the number of contact angles of the fins with the working fluid is one factor that changes the concentration of fluid flow, which influences the heat transfer factor in PV. In contrast to the triangle and quadrilateral fin geometry in the collector, the pentagon geometry in the collector produces a minimum temperature in the Water/Al_2O_3 fluid with a concentration of 2%. Apart from that, it is known that there is a trend of increasing PV temperature along with increasing water/Al_2O_3 fluid concentration. This is because there are differences in the fluid mass flow rate resulting from changes in the density characteristics of the working fluid. The concentration of flow caused by the fins and the increasing density value of the working fluid causes the fluid flow to experience a decrease in the effectiveness of heat transfer in PV to the working fluid.

The difference from using fin geometry in the collector results in a relative PV temperature difference of up to 7% while using Water/Al_2O_3 fluid results in a relative PV temperature difference of up to 4%. Figure 9 displays the PV temperature distribution for each fin geometry in the collector with a fluid concentration of 1% Water/Al_2O_3. The use of pentagon and quadrilateral fin geometry produces similar contours. However, the quadrilateral fin geometry does not have a reddish-orange contour, indicating that a lower PV temperature was produced. In contrast to pentagon geometry, it has more red contours, indicating the high PV temperature produced.

In line with the PV temperature distribution contour, the working fluid temperature distribution contour has the same color trend. Produces a blue contour on the input side and a red contour on the output side in the 38-63°C temperature range. Similar to the PV temperature distribution contour, the working fluid temperature distribution contour using quadrilateral fin geometry in the collector produces a lower temperature. The low temperature of the resulting working fluid is indicated by more blue contours reaching 5 sides on collectors with quadrilateral fins, 4 sides on collectors with pentagon fins, and 3 sides on collectors with pentagonal fins. Apart from that, there is no reddish-yellow contour on the collector with quadrilateral fins, as shown in Figure 10. This will indicate low and high fluid output temperatures.

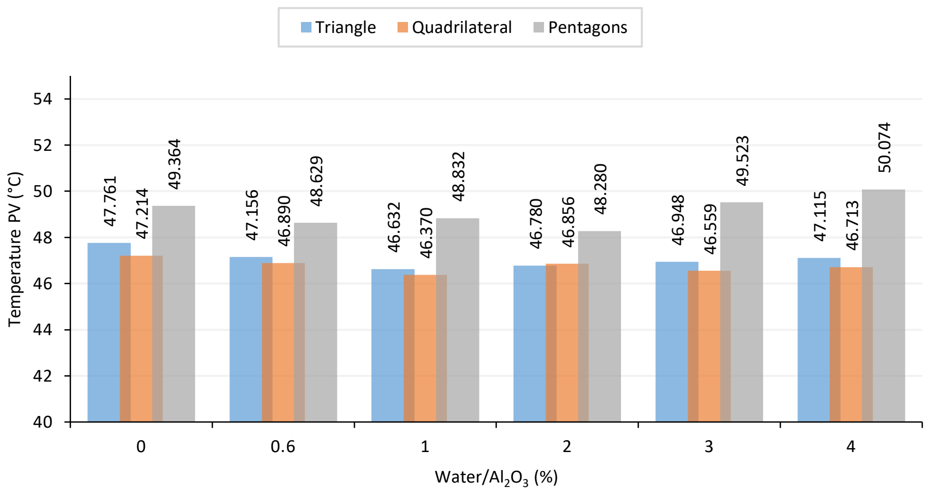


Figure 8. PV temperature in the system studied

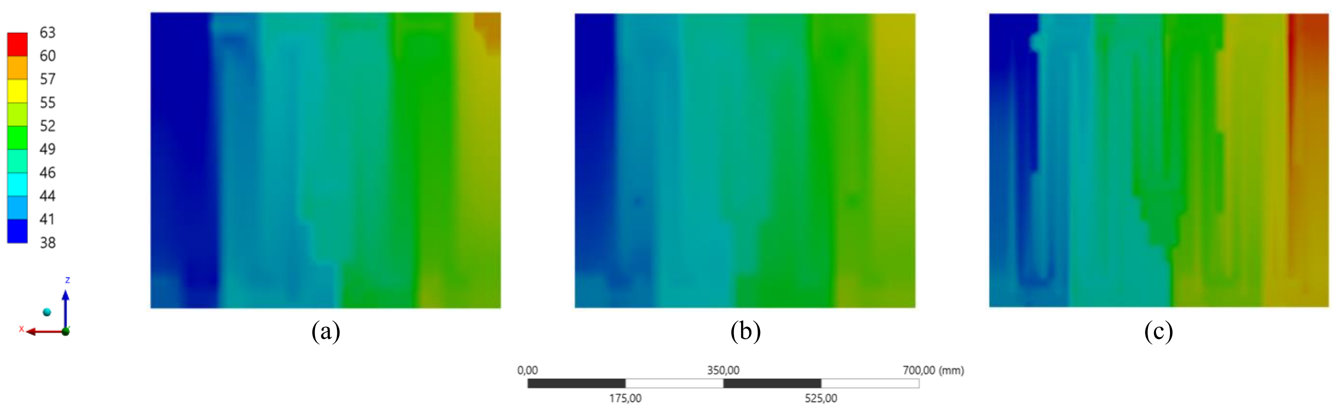


Figure 9. PV temperature distribution contour of finned PV/T system (a) triangle (b) quadrilateral (c) pentagon based on 1% water/Al_2O_3

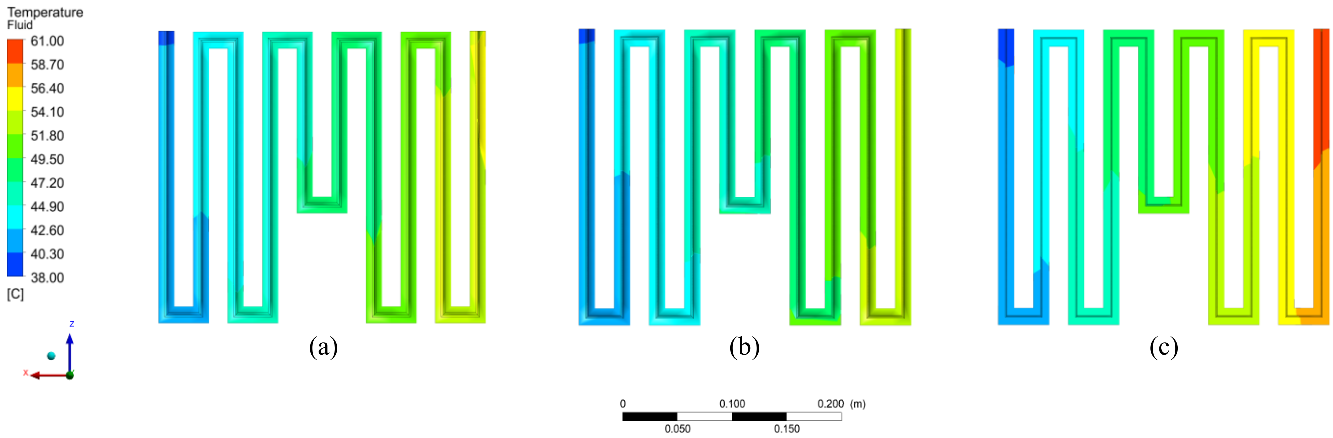


Figure 10. Fluid temperature distribution contour of a finned PV/T system (a) pentagon (b) quadrilateral (c) pentagonal based on 1% water/Al_2O_3

The heat absorbed by the working fluid will result in a difference in the output temperature. Using different fin geometries in the collector and Al_2O_3 fluid concentration impacts the absorption process and heat transfer in the PV to the working fluid. As in Figure 11, the highest working fluid output temperature is produced using a pentagonal fin geometry in a collector with Al_2O_3 fluid with a concentration of 4%, which is 62.48°C. In comparison, the lowest temperature is produced using a quadrilateral fin geometry in a collector with Al_2O_3 fluid with a concentration of 1%. The use of pentagonal fin geometry in the collector makes a much higher output temperature than pentagon and quadrilateral fin geometries for each fluid concentration of Water/Al_2O_3.

When the flow is concentrated, the freedom of fluid flow accelerates the heat transfer process, resulting in a lower fluid output temperature. It can be seen that the use of quadrilateral fin geometry in the collector with 1% Water/Al_2O_3 fluid produces a temperature distribution contour with dominant blue, which indicates low temperature. The fin's angle greatly influences fluid flow control by maintaining fluid flow at a low temperature at the center of the collector. This is supported by a temperature distribution contour with a pentagon geometry, which widens the direction of fluid flow concentration, resulting in a reddish-yellow temperature contour, which indicates the high temperature of the output fluid, as shown in Figure 12.

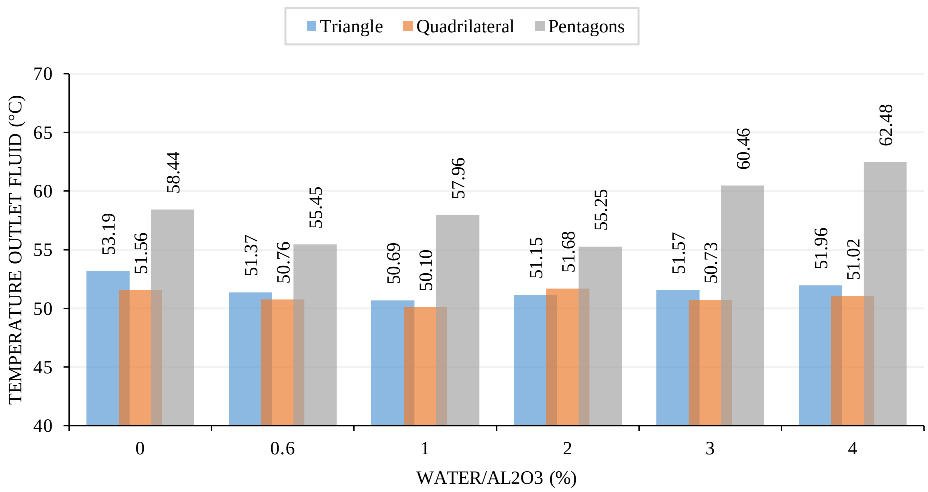


Figure 11. Fluid output temperature in the system studied

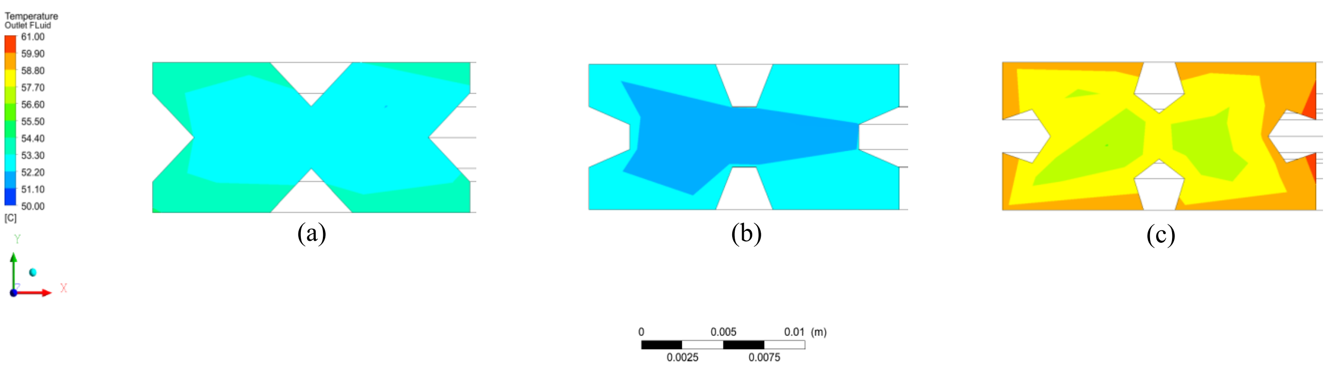


Figure 12. Fluid output temperature distribution contour of a finned PV/T system (a) triangle (b) quadrilateral (c) pentagon based on 1% water/Al_2O_3

5.2 Energy efficiency analysis

The difference in PV temperature produced in the system studied impacts electrical efficiency. The decrease in temperature is in line with the increase in the efficiency of the electricity produced. As in Figure 13, using quadrilateral fin geometry in a collector with Water/Al_2O_3 fluid with a concentration of 1% makes the highest electrical efficiency of 12.83%. A quadrilateral collector has the highest electrical efficiency trend for each Al_2O_3 fluid concentration, while the lowest is when the collector uses a pentagon geometry. The electrical efficiency graph also shows a decreasing trend when the water/al_2O_3 fluid concentration is increased. The difference in relative electrical efficiency in the system studied reached 1.6%.

Data from research related to electrical energy conversion in the system were grouped based on differences in treatment on the geometry of the fins in the collector and the concentration of Al_2O_3 fluid, as in Table 4. Next, the analysis was conducted using two-factor ANOVA without replication to determine the effect of the treatment on electrical energy conversion. Based on the confidence level, namely 95%, the resulting p-value is as in Table 6. It is known that there are significant differences in the results of electrical energy conversion by the three fin geometries in the collector. This is because the resulting p-value is 2.58E-6. In addition, based on the p-value of 0.14, it can be concluded that there is no significant difference in the electrical energy conversion results for the six Water/Al_2O_3 working fluids studied.

In contrast to electrical energy conversion, thermal energy conversion is greatly influenced by the output fluid temperature and the specific heat of the working fluid. This means that the results of thermal energy conversion will be inversely proportional to the results of electrical energy conversion for each treatment studied. As in Figure 14, using a pentagonal fin geometry in a collector with a 4% Water/Al_2O_3 fluid concentration produces the highest thermal energy conversion of 22.28%. In line with the high temperature of the fluid output in the pentagonal fin geometry in the collector for each fluid concentration of Water/Al_2O_3, this treatment produces the highest thermal energy conversion. The resulting relative difference in thermal energy conversion in the system reaches 49.4%.

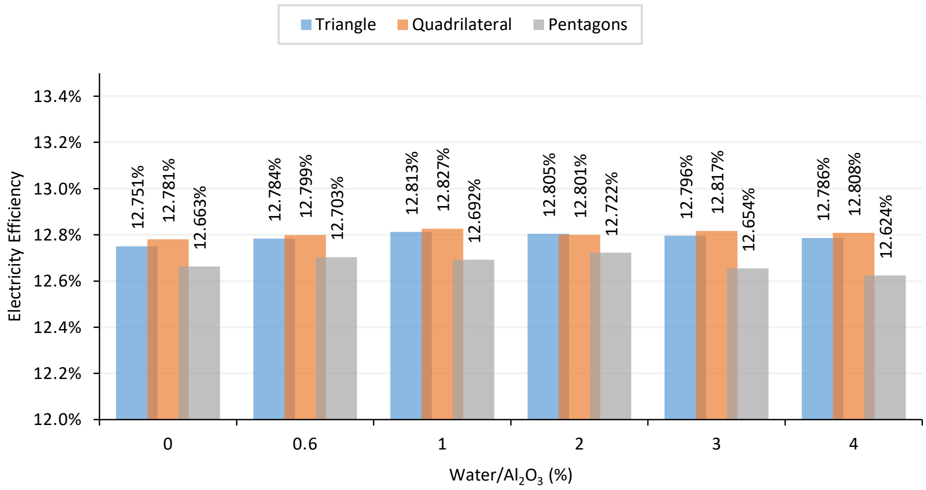


Figure 13. The electrical efficiency of the system studied

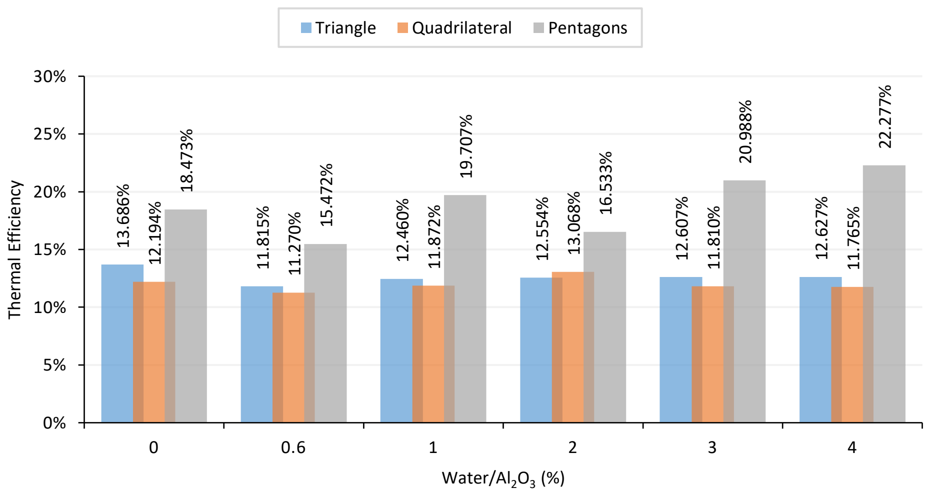


Figure 14. Thermal efficiency of the system studied

Table 4. Comparative design study of fins in collectors

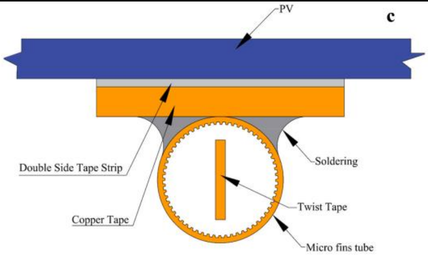
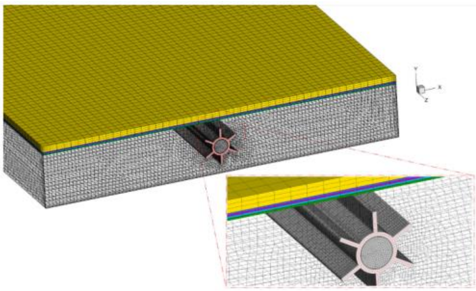
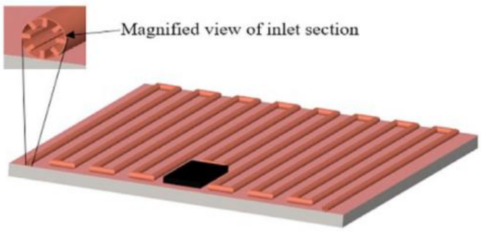
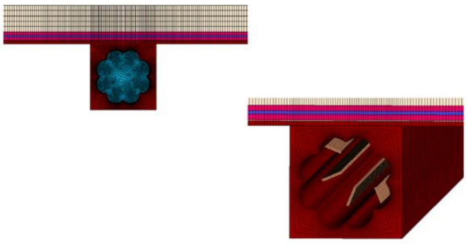
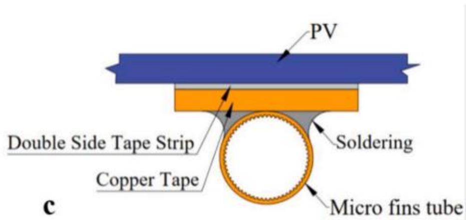
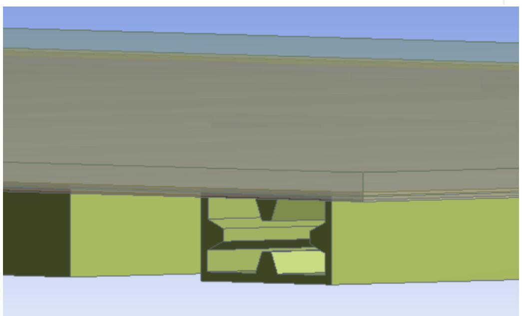
Ref.	Fin Design Drawing	PV/T System - Fluid Concentration	Electrical Efficiency (%)	Thermal Efficiency (%)
[7]		MF-T–NF–0.3 NPCM	10.51	80.8
		MF-T–NF–0.6-NPCM	10.59	83.8
[24]		PVT /PCM	13.81	10-24
[13]		PVT-8S 1%	12.22	47.9
		PVT-8S 2%	12:26	51.7
[25]		6-start rifled PVT system 1%	14.329	52.6
		6-start rifled PVT system 2%	14.393	57.7
[26]		case 6 with GNP nanofluid (0.1 %)	15.32	55.2
[27]		PVT NF NPCM	9.6	89
Study		PV/T Fin Quadrilateral – 0.6%	12.80	11.27
		PV/T Fin Quadrilateral – 1%	12.83	11.87
		PV/T Fin Quadrilateral – 2%	12.80	13.07

Table 5. Data on electrical energy conversion results for the system studied

SUMMARY	Count	Sum	Average	Variance
Triangles	6	0.767344367	0.127890728	4.68454E-08
Quadrilateral	6	0.768325778	0.128054296	2.56874E-08
Pentagons	6	0.760587628	0.126764605	1.30267E-07
Water/Al_2O_3 0%	3	0.381946861	0.12731562	3.76029E-07
Water/Al_2O_3 0.6%	3	0.382860213	0.127620071	2.6444E-07
Water/Al_2O_3 1%	3	0.383321646	0.127773882	5.50553E-07
Water/Al_2O_3 2%	3	0.383277152	0.127759051	2.14976E-07
Water/Al_2O_3 3%	3	0.382665232	0.127555077	7.81729E-07
Water/Al_2O_3 4%	3	0.382186668	0.127395556	1.01472E-06

Table 6. Results of two-factor anova without replication on the electrical energy conversion of the system studied

Sources of Variation	SS	df	M.S	F	P-value	F crit
Fin geometry in the collector	5.91643E-06	2	2.95821E-06	60.5611402	2.57999E-06	4.102821015
Fluid Concentration of Water/Al_2O_3	5.25532E-07	5	1.05106E-07	2.151760979	0.1415849	3.32583453
Error	4,88467E-07	10	4,88467E-08			
Total	6.93043E-06	17				

Table 7. Data on thermal energy conversion results for the system studied

SUMMARY	Count	Sum	Average	Variance
Triangles	6	0.701659693	0.116943282	0.00010217
Quadrilateral	6	0.665885973	0.110980995	5.13359E-05
Pentagons	6	1.046153208	0.174358868	0.000390596
Water/Al_2O_3 0%	3	0.443528968	0.147842989	0.001076201
Water/Al_2O_3 0.6%	3	0.385573907	0.128524636	0.000522105
Water/Al_2O_3 1%	3	0.391456994	0.130485665	0.001504364
Water/Al_2O_3 2%	3	0.374711738	0.124903913	0.000370062
Water/Al_2O_3 3%	3	0.403591937	0.134530646	0.002042482
Water/Al_2O_3 4%	3	0.41483533	0.138278443	0.002691047

Table 8. Results of two-factor anova without replication on the thermal energy conversion of the system studied

Sources of Variation	SS	df	M.S	F	P-value	F crit
Fin geometry in the collector	0.014697706	2	0.007348853	42.85504192	1.24512E-05	4.102821015
Fluid Concentration of Water/Al_2O_3	0.001005692	5	0.000201138	1.172943763	0.386644357	3.32583453
Error	0.001714816	10	0.000171482			
Total	0.017418214	17				

All data from careful thermal energy conversion analysis have been successfully grouped as in Table 7. This table shows the amount of data, number of results, average, and variance. From the resulting data, a two-factor ANOVA calculation without replication was carried out with a confidence level of 95%. Calculations were carried out to determine the effect of the treatment of using fin geometry in the collector and Water/Al_2O_3 fluid on the system's thermal energy conversion results. Because the p-value as in Table 8 for the treatment of fin geometry in the collector and the Water/Al_2O_3 fluid concentration is 1.25E-5 and 0.39, it can be concluded that the three fin geometries in the collector have a significant influence on the results of thermal energy conversion. In contrast, the sixth fluid concentration, Water/Al_2O_3, does not significantly affect the thermal energy conversion results.

A comparison of research studies was carried out to determine the performance results caused by differences in the design of the fins in the collector of the nanofluid-based PV/T system, as shown in Table 4. Comparisons can only partially be made. Comparison of results between research studies with other research references. That is because many aspects of boundary conditions affect different systems. However, based on the boundary condition approach, the research resulted in a range of 9-15% of electrical efficiency conversions. The best nanofluid concentration is in the 1-2% range.

6. CONCLUSION

This study examines the impact of fin geometry on the energy conversion of a Water/Al_2O_3-based PV/T system. The research was conducted using modeling simulations using a 3D CFD approach and ANSYS Fluent software coupled with ANSYS Steady State Thermal. Modeling treatments using three different fin geometries and five Water/Al_2O_3 concentrations. This study found quadrilateral fin geometries produced the lowest PV temperatures, followed by pentagon and pentagonal fin geometries for each concentration. Differences in fin geometry affect the heat transfer factor in PV, resulting in relative PV temperature differences of up to 7%. This research also found that the amount of heat the working fluid absorbs affects the output temperature.

Electrical and thermal energy conversion analyses were carried out based on the results of capital studies in the form of PV temperature and fluid output. The results show that the temperature decreases with increasing electrical efficiency. Quadrilateral fin geometry with 1% Water/Al_2O_3 fluid produces the highest electrical efficiency of 12.83%. This research also found that internal energy conversion was inversely proportional to the results of electrical energy conversion for each treatment. Pentagon fin geometry with 4% Water/Al_2O_3 fluid produces the highest conversion of 22.28%.

This study used two-factor ANOVA without replication to analyze the effect of treatment on electrical and thermal energy conversion. The results showed significant differences in results for the three fin geometries on the collector. However, no significant differences were found for the six Water/Al_2O_3 working fluids studied. In addition, the research results show that the three fin geometries significantly influence the thermal energy conversion results, while the six Water/Al_2O_3 fluid concentrations have no effect.

This research has identified several obstacles that require further study to overcome. The subsequent research will validate the results of Computational Fluid Dynamics modeling and simulation, testing hybrid PV solar cell systems using Al_2O_3 nanofluid-based finned thermal collectors under actual environmental conditions. The next step is to experiment with various thermal collector fin geometries based on the research boundary conditions, using water dispersion and Al_2O_3 nanoparticles to produce nano-fluid as the working fluid for each concentration in the PV/T system. Expansion of heat transfer contact with holes in the fins can also be considered.

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