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Effect of Angle and Flow Diameter of Internal Fins on the Performance of Photovoltaic Thermal System Integrated with Palm-Wax PCM

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***Abstract* - Photovoltaic/thermal hybrid (PVT) is a solar panel system capable of producing electrical and thermal energy. This study aims to examine the effects of the internal fin diameter and angle on the surface temperature of solar panels and the water outlet temperature in the pipe. To increase heat absorption in solar panels, palm wax PCM is used. There are five parallel pipes in the palm-wax PCM, absorbing heat from it. This research uses ANSYS Fluent software, with variations in the internal flow diameter and the angular distance between fins. The inner flow diameter consists of 2, 3, 4, 5, and 6 mm, while the angle between the fins consists of 10°, 15°, 20°, and 25°. The results are obtained as PV Cell wall temperature, outlet temperature, and the mass of melted PCM during a three-hour simulation. Based on the simulation results, it can be concluded that the use of PCM and variations in the inner finned tube reduce PV Cell temperature.**

Keywords: PVT, PCM, solar cell, internal fin, palm-wax.

I. INTRODUCTION

In recent years, energy demand has increased globally due to rapid industrialization and urbanization. Solar energy is a safe, low-cost renewable energy source that can meet this increasing demand [1]. Thermal photovoltaic (PVT) systems are devices that convert solar radiation into both electrical and thermal energy. In a PVT system, a collector is installed to absorb heat [2]. Compared with PV systems alone, PVT systems not only have higher electrical energy but can also produce thermal energy. Different parameters, such as glass cover [3], thermal collector design [4], pressure drop [5], mass flow rate, and working fluid type [6], can influence the performance of these systems.

Over the last decade, several researchers have used nanofluids as working fluids in PVP systems instead of water or air to improve performance. Some basic fluid thermodynamic properties, such as heat transfer coefficient and thermal conductivity, are enhanced by the dispersion of nanoparticles in the basic fluid [7]. Nanoparticles can be classified into various types, including metals, metal oxides, metal carbides, and carbon nanotubes (CNTs) [8]. Nanofluids consist of nanoparticles with high thermal conductivity, and those with high aspect ratios exhibit higher thermal performance [9].

Integrating phase change materials (PCMs) with thermal photovoltaic systems is another approach to improving their performance [10]. PCMs can absorb sensible heat, and when their temperature reaches the melting point, they begin to melt and absorb latent heat [11]. The PCM temperature does not change during the melting process, but after the phase change is complete, the temperature increases [12]. Ma *et al.* [13] present a literature review on PCM applications in PV units to improve their performance and conclude that PCM use may not be economically feasible unless combined with the utilization of thermal energy from PCM [14, 15]. Several studies have been conducted on thermal photovoltaic systems integrated with phase change materials (PVT/PCM). Apart from that, the use of internal fins on pipes inside the solar panel can also increase PVP efficiency, as these fins reduce the PV cell's surface temperature.

II. BASIC THEORY

A solar panel is a device that converts sunlight energy (photons) into electrical energy through the photovoltaic (PV) process. This process takes advantage of the properties of semiconductors, such as silicon, which can release electrons when hit by photons. These liberated electrons are then collected and passed through an external circuit, producing an electric current.

When using PV, especially in tropical regions, the surface of these solar panels can reach high temperatures, significantly reducing their efficiency. Therefore, it is necessary to take steps to lower the temperature, especially if it is used as a roof-mounted power plant. A great deal of research has been conducted to reduce this temperature. One way is to use heat-absorbing materials that change phase at low temperatures.

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Phase change material (PCM) is a material capable of storing and releasing heat energy during a phase change, such as from solid to liquid or liquid to gas. PCM can absorb and release large amounts of heat energy within a narrow temperature range. This makes PCMs ideal for use in thermal energy storage applications.

Internally finned pipe, or internal fin grooved pipe, is a pipe that has fins on the inside. These fins increase the surface area of the pipe, thereby improving heat transfer between the pipe and the fluid flowing within it. It can be used to increase the efficiency of heating and cooling systems. Grooved pipe fins are made from various materials, such as aluminum, copper, and stainless steel. The shape and size of the fins may also vary. The selection of the appropriate fin material and design depends on the specific application of the pipe.

III. METHODOLOGY

This research was carried out computationally using finite-volume techniques with the Ansys Fluent application. The object is a commercial solar panel equipped with an absorber, a water-filled pipe, and palm wax PCM, as shown in Figure 1. The geometry of the solar panel has an area of 53 x 35 cm and consists of layers of several materials, including PCM, copper absorber, Tedlar, EVA, PV Cell, and glass, each with different thicknesses. Apart from that, there are 5 rows of pipes which have an outer diameter of 10 mm and an inner diameter of 9 mm. To increase the heat transfer rate between the PCM and water, internal fins with the geometry shown in Figure 2 are added inside the pipe. The details of geometry are presented in Table 1.

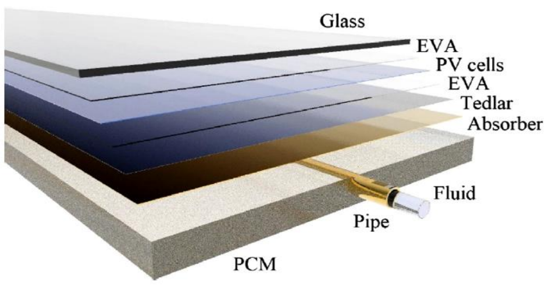

Figure 1: Geometry domain for simulation

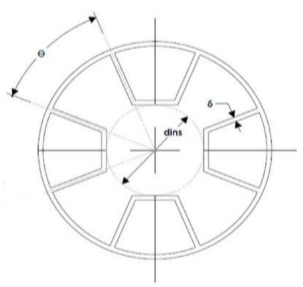

Figure 2: Cross-section of internal fin

Table 1: Detailed geometry of the internal fin

Pipe Flow Diameter	2, 3, 4, 5, and 6 mm
Number of Pipes	2
Pipe Inside Diameter	9mm
Pipe Outside Diameter	10mm
Fin Angle	10º, 15º, 20º, and 25º
Fin Thickness	1mm
Fin Shape	Longitudinal Fin
Fin Amount	4

The simulation procedure begins with creating a 3D model in SolidWorks, as depicted in Figure 3. Then it was followed by mesh generation and computational modeling using Ansys Fluent. Based on grid independence test, the number of elements used in this research is around 1.8 million, as shown in Figure 4, with an average orthogonality of 0.680 and an average skewness of 0.318. The setup for problem solving uses a laminar viscosity model, as well as solidification and melting processes. The simulation was performed using a SIMPLE pressure-velocity coupling. In this calculation, 3600 simulations were carried out with a time step of 1 second, with a maximum of 50 iterations per time step.

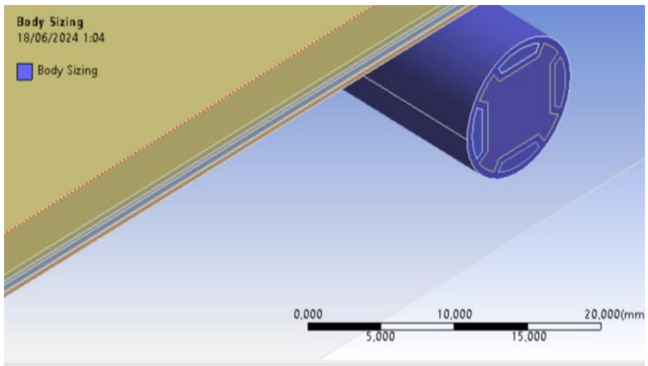

Figure 3: 3D model created in Solid Works

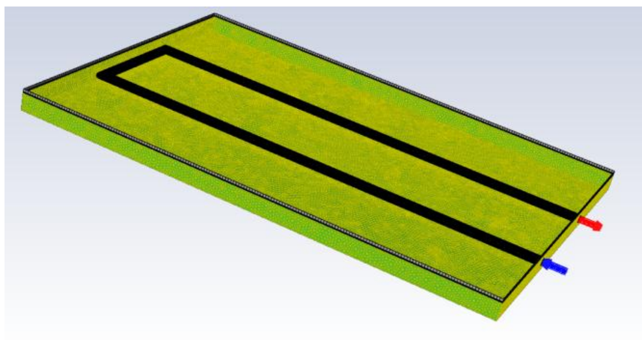

Figure 4: Mesh generation

The materials used in this simulation are divided into two, namely Fluid and Solid. The material is shown in Table 2, and the property values are reported in the reference journal.

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Table 2: Properties of the materials

Type of Material	Material	Aplication on geometry
Fluid	Water Liquid	Fluid
	Palm Wax	PCM
Solid	Acrylic	Wall of PCM
	Copper	Pipe wall
		Absorber
		Absorber wall
	EVA	EVA-1 wall
		EVA-2 wall
	Glass	Glass wall
		Hot wall
	PV Cell	PV Cell wall
	Tedlar	Tedlar wall

IV. RESULTS AND DISCUSSIONS

Based on the simulation results via ANSYS Fluent which consists of 5 variations in internal flow diameter (2, 3, 4, 5, 6 mm) and also variations in the angular distance between fins (10°, 15°, 20°. 25°), 3 graphs are obtained in the form of graph of the relationship between outlet temperature versus time, graph of PVCell wall temperature versus time, and graph of melted PCM versus time.

4.1 Internal flow diameter 2 mm

Based on the fluid outlet temperature, the graphical results presented in Figure 5 below indicate that the highest outlet temperature was obtained for the 25° configuration, followed by 15°, 20°, and 10°. This trend suggests that the inclination angle significantly influences the thermal performance of the fluid flow within the system.In contrast, the graphical results for the PV cell wall temperature, as depicted in Figure 6, show a different trend. The PV cell wall temperature decreases in the following order: 15°, 25°, 20°, and 10°. These results indicate that the inclination angle affects not only the fluid heating characteristics but also the heat dissipation behavior of the PV cell surface.

4.2 Internal flow diameter 3 mm

The relationship between the inclination angle and the fluid outlet temperature is illustrated in Figure 7. The results show that the highest outlet temperature occurs at an inclination angle of 20°, followed by 15°, 10°, and 25°. These variations indicate that the inclination angle plays an important role in determining the thermal energy transferred to the working fluid.Figure 8 presents the corresponding temperature distribution on the PV cell wall. In contrast to the outlet fluid temperature trend, the PV cell wall temperature reaches its highest value at an inclination angle of 10°, followed by 25°, 15°, and 20°. This behavior suggests that the effectiveness of heat removal from the PV surface differs among the tested inclination angles, resulting in distinct temperature characteristics of the PV cell.

4.3 Internal flow diameter 4 mm

The temperature profiles obtained at the pipe outlet are summarized in Figure 9. The results indicate that the outlet fluid temperature reaches its maximum at an inclination angle of 20°, while lower temperatures are recorded at 10°, 25°, and 15 °. This distribution suggests that the inclination angle affects the amount of thermal energy extracted by the circulating fluid.Figure 10 shows the variation in PV cell wall temperature under the same operating conditions. The highest PV cell temperature is observed at 15°, followed by 20°, 10°, and 25°. The difference between the temperature rankings of the fluid outlet and the PV cell wall implies that the thermal energy generated within the PV/T system is distributed differently between the absorber surface and the working fluid depending on the inclination angle.

4.4 Internal flow diameter 5 mm

Figure 11 compares the working-fluid outlet temperatures at the investigated inclination angles. The results indicate that the 20° configuration delivers the highest outlet temperature, followed by 10°, 25°, and 15°. This finding suggests that the collector orientation has a considerable impact on the heat gained by the fluid as it flows through the system.The thermal behavior of the PV cell surface is presented in Figure 12. Unlike the fluid outlet temperature, the PV cell wall temperature follows a different trend, with the highest value recorded at 20°, followed by 25°, 10°, and 15°. The variation in temperature distribution reflects the influence of inclination angle on the balance between solar energy absorption and heat removal from the PV/T module.

4.5 Internal flow diameter 6 mm

The thermal response of the working fluid at the collector outlet is shown in Figure 13. Among the investigated inter-fin angles, the 20° configuration exhibits the highest outlet temperature. Meanwhile, the temperatures obtained at 10°, 15°, and 25° differ only slightly, implying that changes in inter-fin angle beyond the optimum condition have a limited effect on fluid heating performance.As depicted in Figure 14, the PV cell wall temperature follows a different pattern. The maximum temperature is recorded at an inter-fin angle of 10°, with progressively lower temperatures at 20°, 15°, and 25°. The discrepancy between the fluid and PV cell temperature trends indicates that the mechanisms governing heat absorption and heat extraction are influenced differently by the inter-fin geometry.

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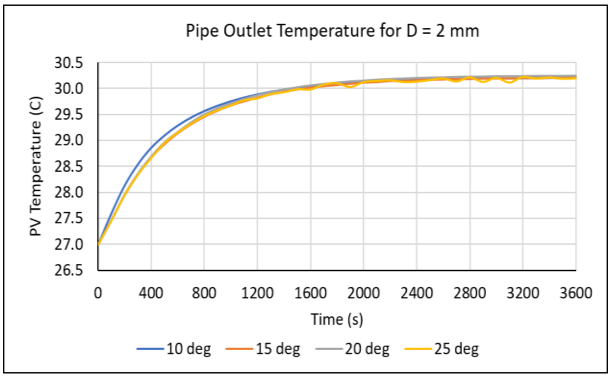

Figure 5: Outlet temperature for d_{ins} = 2 mm

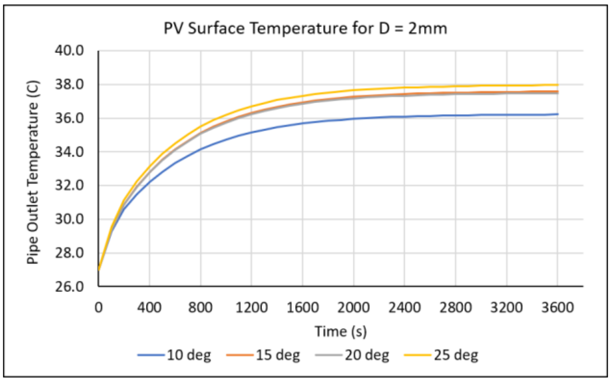

Figure 6: PV temperature for d_{ins} = 2 mm

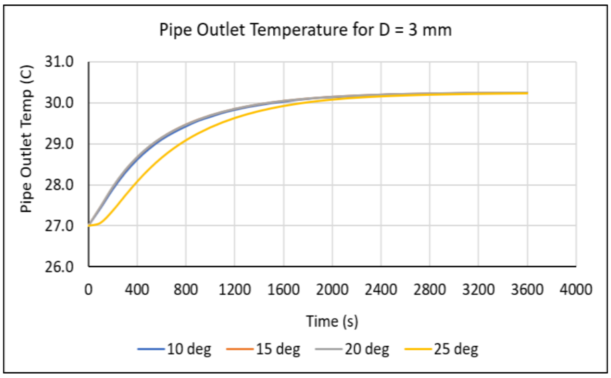

Figure 7: Outlet temperature for d_{ins} = 3 mm

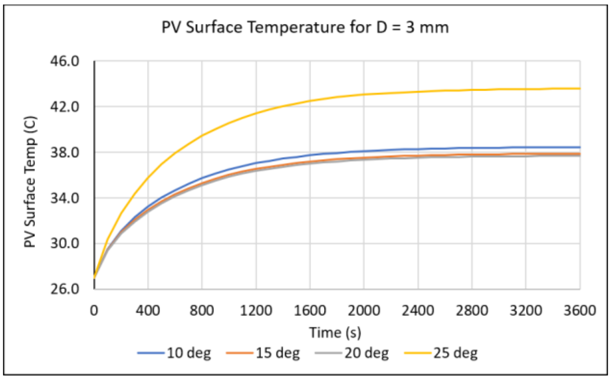

Figure 8: PV temperature for d_{ins} = 3 mm

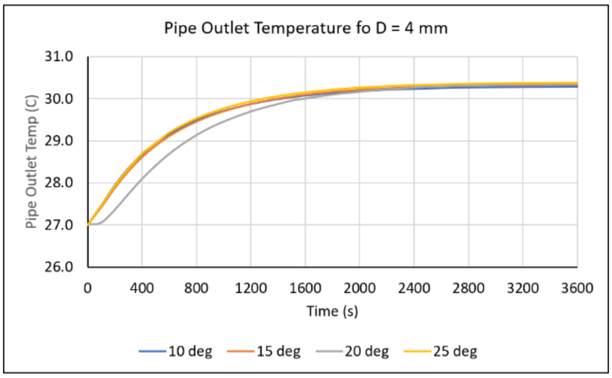

Figure 9: Outlet temperature for d_{ins} = 4 mm

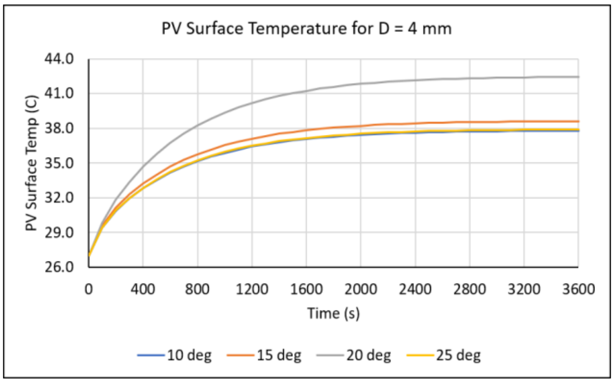

Figure 10: PV temperature for d_{ins} = 4 mm

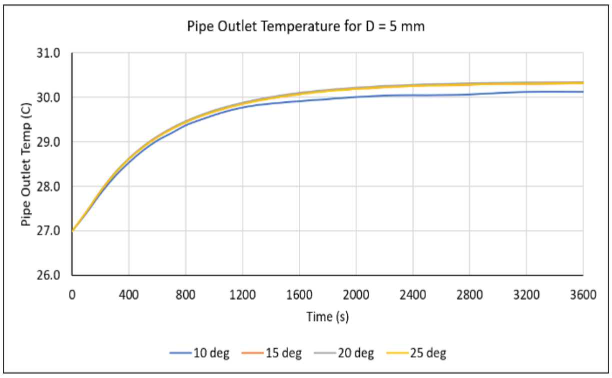

Figure 11: Outlet temperature for d_{ins} = 5 mm

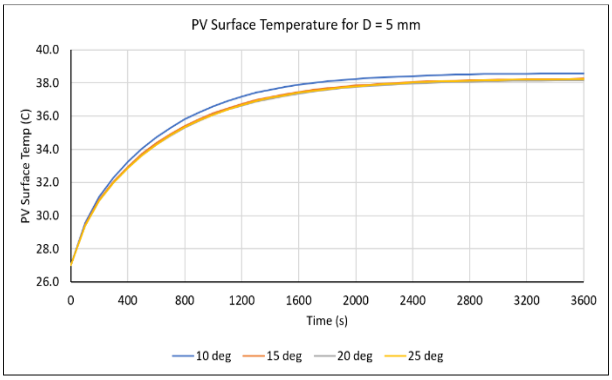

Figure 12: PV temperature for d_{ins} = 5 mm

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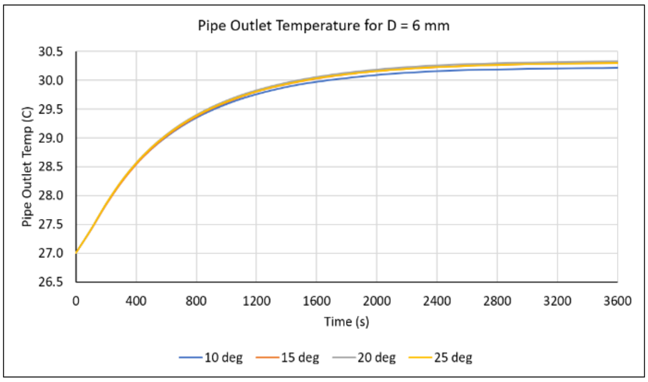

Figure 13: Outlet temperature for d_{ins} = 6 mm

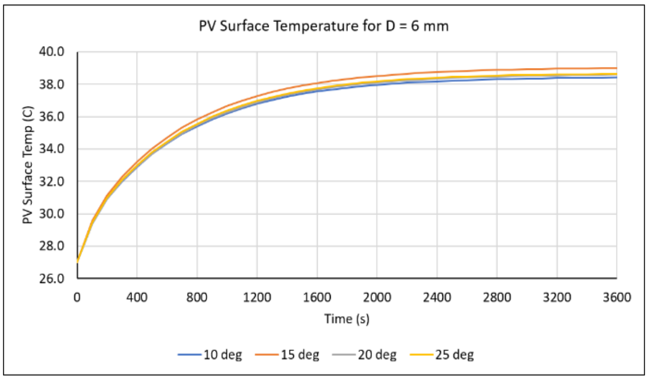

Figure 14: PV temperature for d_{ins} = 6 mm

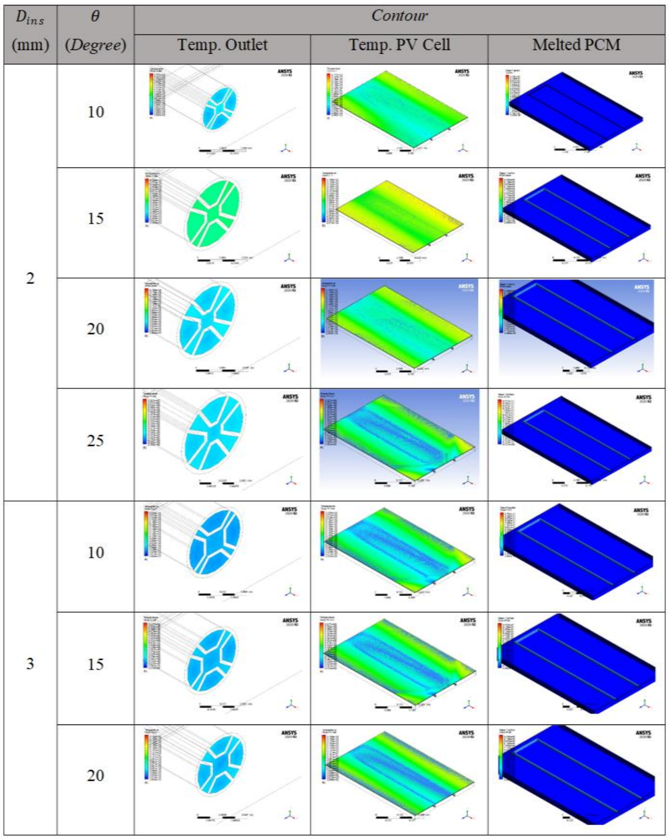

Figure 15: Temperature contour and melted PCM for dins 2 and 3 mm

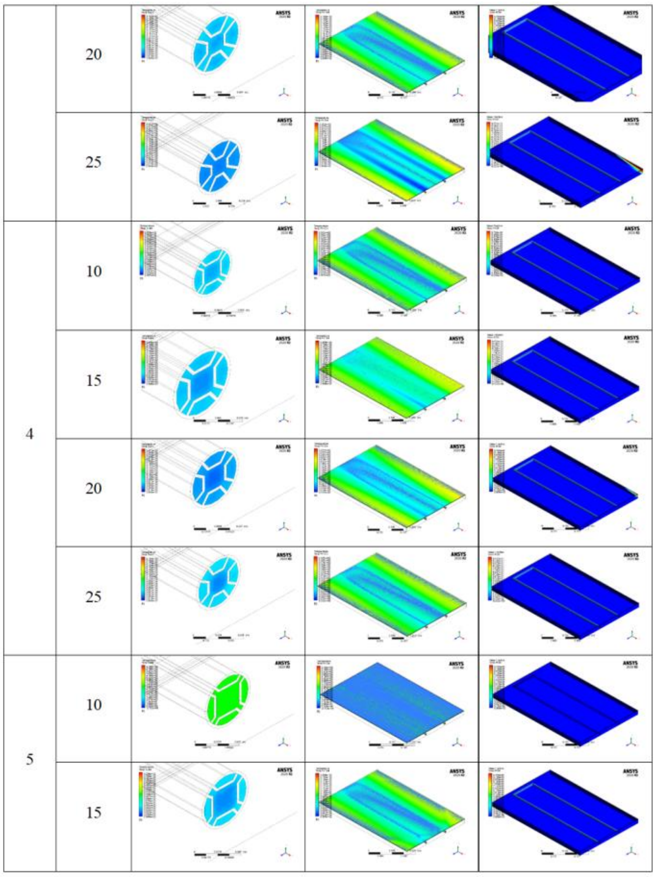

Figure 16: Temperature contour and melted PCM for dins 4 and 5 mm

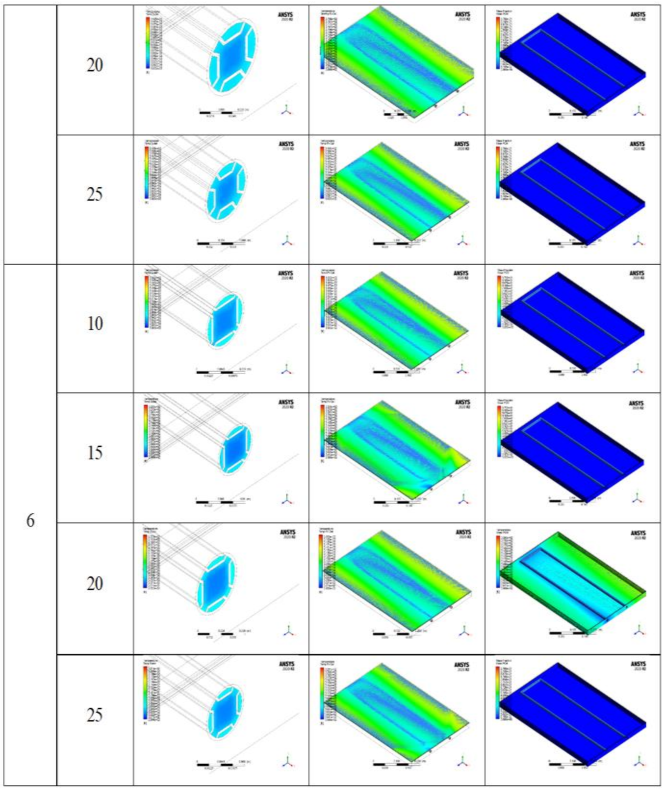

Figure 17: Temperature contour and melted PCM for dins 5 and 6 mm

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The temperature contours and PCM melting patterns obtained for the investigated configurations are depicted in Figures 15–17. It is evident that changes in the inner-flow diameter and fin angular spacing substantially affect the thermal behavior of the PV/T-PCM system. These geometric parameters influence the heat-transfer area, fluid-flow characteristics, and thermal distribution within the PCM domain, resulting in different melting rates and temperature profiles. Therefore, the inner-flow diameter and fin angular spacing can be regarded as key design variables that determine the thermal efficiency of the internal fin structure and its capability to enhance heat extraction and thermal energy storage.

V. CONCLUSION

Research aimed at analyzing the effects of variations in the inner-flow diameter and the angular distance between the fins on a palm-wax PCM with a configuration of 5 parallel pipes has been successfully carried out. Using ANSYS Fluent, data were obtained for the outlet temperature, PV Cell wall temperature, and the mass of PCM that melted over a 3-hour simulation. Based on the simulation results, it can be concluded that the use of PCM and variations in the inner finned tube reduce PV Cell temperature, enabling solar panels to function optimally without overheating.

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