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Simulation and Efficiency Enhancement of Solar PV Panel Using Cooling Fins

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Abstract- The study on the cooling effect of attached fins of different geometries on photovoltaic (PV) panels using Computational Fluid Dynamics (CFD) simulation is motivated by the increasing demand for efficient cooling solutions in solar energy systems. This study provides a comprehensive analysis of parametric studies on fins attached to photovoltaic (PV) solar panels, focusing on enhancing their thermal performance and efficiency. The utilization of fins in PV systems is a critical area of research aimed at mitigating the adverse effects of temperature rise on solar panel efficiency. This study use various fin geometries, including rectangular, trapezoidal, and triangular fins, and examines their impact on the thermal regulation of PV panels.

Keywords- Fins, PV solar panel, ANSYS, CFD

I. INTRODUCTION

The study on the cooling effect of attached fins of different geometries on photovoltaic (PV) panels using Computational Fluid Dynamics (CFD) simulation is motivated by the increasing demand for efficient cooling solutions in solar energy systems. With the growing utilization of PV panels worldwide, maintaining optimal operating temperatures becomes crucial for their performance and longevity. The research aims to investigate how various fin shapes and configurations can enhance heat dissipation from the PV panels, thereby improving their efficiency and reliability. By employing CFD simulations, the study seeks to provide insights into the thermal behavior of different fin geometries under varying environmental conditions, offering valuable guidance for the design and optimization of cooling systems for PV installations.

This study delves into a critical aspect of photovoltaic (PV) system performance: temperature management. As solar panels convert sunlight into electricity, they generate heat, which can adversely affect their efficiency and lifespan if not properly regulated. Attached fins, strategically positioned on the panels, have emerged as a promising solution for dissipating excess heat and maintaining optimal operating temperatures. However, the effectiveness of fins can vary significantly based on their geometry, including factors such as shape, size, and orientation. Through comprehensive Computational Fluid Dynamics (CFD) simulations, this research aims to explore the intricate interplay between different fin configurations and their cooling capabilities. By systematically analyzing various fin geometries under diverse environmental conditions, such as solar irradiance levels and airflow patterns, the study endeavors to uncover the most efficient cooling strategies for PV systems. Ultimately, the findings of this investigation hold significant implications for the advancement of solar energy technology, paving the way for enhanced performance, reliability, and sustainability of PV installations worldwide.

In addition to exploring the performance of different fin geometries, this study also aims to deepen our understanding of the underlying fluid dynamics involved in the cooling process. By simulating the airflow around the PV panels with attached fins, researchers can visualize how air circulates over and around the surfaces, carrying away heat through convective cooling. Understanding these flow patterns is crucial for optimizing fin design to maximize heat transfer efficiency. Furthermore, the study will investigate the impact of various environmental factors, such as wind speed and ambient temperature, on the effectiveness of fin cooling. This comprehensive analysis will not only provide valuable insights into the thermal behavior of PV panels but also inform the development of advanced cooling strategies tailored to specific operating conditions. Ultimately, the research outcomes have the potential to drive innovation in renewable energy technologies, making solar power more economically viable and environmentally sustainable for widespread adoption in the transition towards a greener future.

II. RESEARCH METHODOLOGY

1. Physical Model

The schematic model of the present study is shown in Fig. 1 which investigate the a passive cooling technology using fins attached to the back of the PV module. Further, three size of fins were considered in this study.

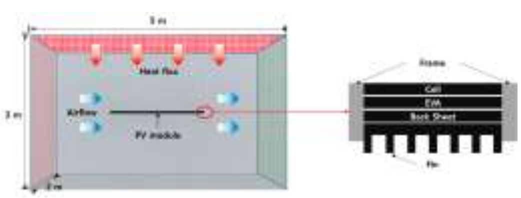


Fig. 1: Schematic diagram of the simulation model (Kim and Nam, 2019)

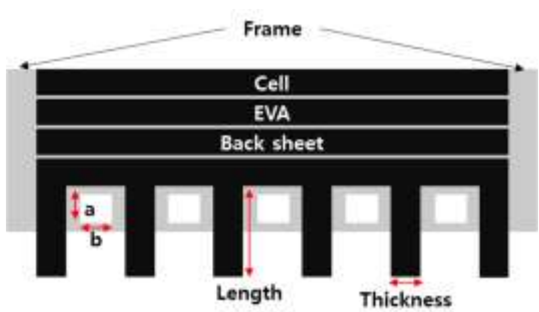


Fig. 2: The configuration of fins and slits (Kim and Nam, 2019)

The simulation model was constructed to analyze the effect of the airflow around the PV module by referring to the indoor test that used a solar simulator. The PV module was inserted into a domain (air) of dimension 2 m × 3 m × 5 m (Figure 2). Moreover, the physical conditions were based on the three-dimensional steady state, and the spatial grid used was the polyhedral mesher capable of multi-region conformal meshing.

Governing Equation

The steady-state fluid flow characteristic in the three-dimensional computational domain can be described using the following governing incompressible fluid flow equations.

Continuity Equation

$$\frac{\partial u_i}{\partial x_i} = 0$$

Momentum Balance without Gravity Force

$$\rho_{u_i}\frac{\partial u_i}{\partial x_i} = -\frac{\partial P}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j}$$

Energy equation

$$\rho C_p \frac{\partial (u_i T)}{\partial x_i} = \frac{\partial}{\partial x}\left(\lambda_{eff}\frac{\partial T}{\partial x_i}\right)$$

In conservative form, the partial differential equations for the RNG k−ε model are Turbulent kinetic equation

$$\rho u_j \frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\mu_{eff}\alpha_k \frac{\partial k}{\partial x_j}\right] + \tau_{ij}\frac{\partial u_i}{\partial x_j} - \rho\varepsilon + G_K + \mathrm{G_b}$$

Turbulent kinetic dissipation equation

$$\rho u_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\mu_{eff}\alpha_\varepsilon \frac{\partial \epsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\partial \varepsilon}{\partial x_j} + C_{1\varepsilon}\frac{\varepsilon}{K}(G_K + C_{3\varepsilon}\mathrm{G_b}) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{K}$$

The above Reynolds Averaged Navier-Stokes (RANS) turbulence models offer the most economic approach for computing complex turbulent industrial flows. Generally, the Navier-Stokes equations describe the motion of the turbulent flow. However, it is too costly and time-consuming to solve these equations for complex flow problems [26]. Alternatively, two methods have been suggested in the past: (i) Large Eddy Simulation (LES) where the large energy containing eddies are simulated directly while the small eddies are accounted for by averaging. The separation of large and small eddies requires following, (ii) Reynolds averaging (RANS) where all eddies are accounted for by Reynolds stresses obtained by averaging the Navier-Stokes equations (time averaging for statistically steady flows, ensemble averaging for unsteady flows).

3. Boundary Conditions

In the present investigation, the commercial CFD software FLUENT 6.3, which is based on the finite volume method, is used for the numerical computation, and the SIMPLE algorithm is used for finding a solution for the coupling between the pressure and velocity. The finite-element model is built and meshed using the software Gambit, and unstructured grids are used. The tetrahedral grid is used for meshing the models, and the grid in the region near the tube wall, which is highly refined, is considered as the boundary layer. Fig. 3 shows the meshing grid. In this study, a parameter study was conducted according to the shape of the fins to analyze the cooling performance of the fins attached at the bottom of the PV module. In addition, a simulation model with slits, which can improve the cooling performance of the fins through the formation of active airflow distribution at the bottom of the fins and module, was also considered. The convergence criterion is that all the norms of the residuals for the continuity, momentum, and energy equations should be less than 10-6.

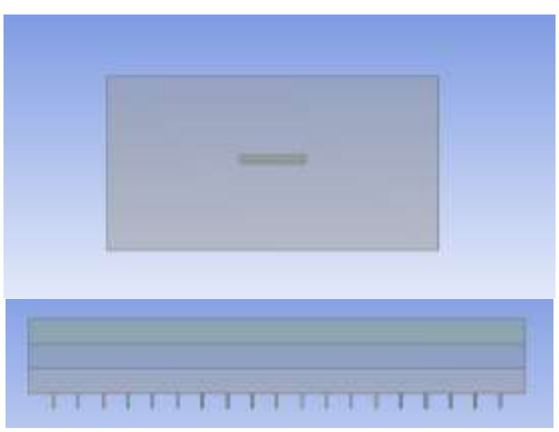


Fig. 3: CFD model

4. Choosing the Physical Properties

The definition of physical properties (thermal conductivity, density, viscosity, specific heat) of fluids and solids is a necessary factor for setting up the model. The PV module implemented through simulation consisted of cells, EVA (ethylene vinyl acetate), a back sheet, and fins, except glass. In other words, the effects of transmission bodies, such as glass and EVA, on the transmissivity of solar irradiance were ignored. The two sides of the domain were set as the velocity inlet and pressure outlet for the airflow. On the top surface, the heat flux was set as the boundary condition (Table 1). The values of the heat flux and velocity were set to 600 W/m2 and 0.5 m/s, which were in the effective range under the NOCT condition. In addition, the interface of each layer was assumed to be in full contact, and the contact resistance was set to 0 m2K/W. Table 2 shows the thermal properties of each component entered into the simulation of the PV module.

Table 1: Simulation conditions

Heat flux, W/m^2	Velocity inlet (m/s)	temperature, °C	temperature, °C	Resistance, m^2K/W
600	0.5	26.84	26.84	0

Table 2: Thermophysical properties

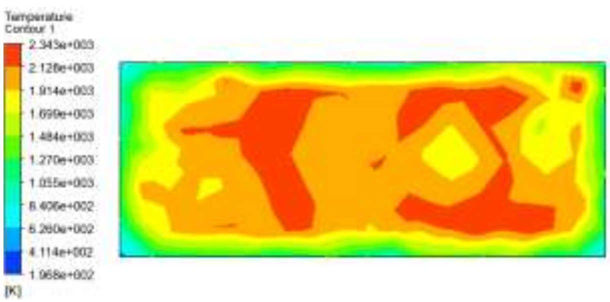
Components	Density (Kg/m^3)	Thickness, mm	Specific heat (J/Kg^oC)	Thermal conductivity, (W/mk)
Cell (Si)	2330	10	677	148
EVA	960	10	2090	0.35
Frame (Al)	2702	60	903	237
Back sheet	1200	1	1250	0.2
Fin (Cu)	8900	3	385	400

III. RESULTS AND DISCUSSION

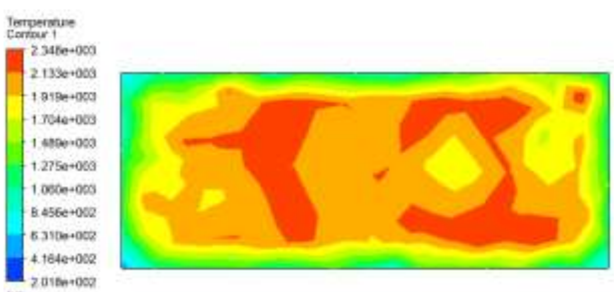
1. Temperature Contour

At a velocity of 0.5 m/s, the temperature distribution in a chamber with a rectangular fin attached to a surface undergoes a complex but predictable pattern influenced by several factors. Initially, as air flows over the surface of the fin, it absorbs heat from the surface due to convective heat transfer.

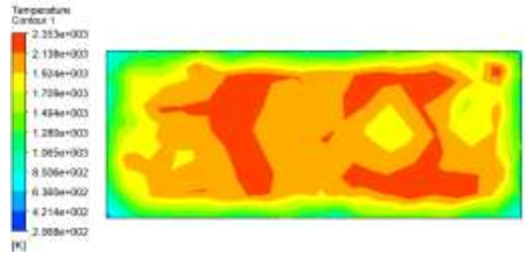
This results in a decrease in temperature near the surface of the fin. As the air moves along the length of the fin, it carries this heat away, leading to a gradual increase in temperature downstream. However, the temperature distribution is not uniform across the chamber. Near the leading edge of the fin, where the airflow first encounters the surface, the temperature drop is more pronounced due to the direct exposure to the cooler incoming airflow. Conversely, at the trailing edge of the fin, where the airflow has already absorbed heat along its path, the temperature rise is more significant.



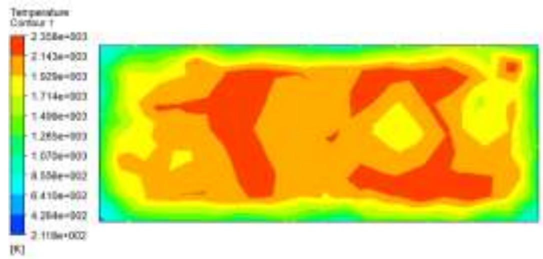
(a) Temperature distribution in chamber for rectangular fin at velocity of 0.5m/s



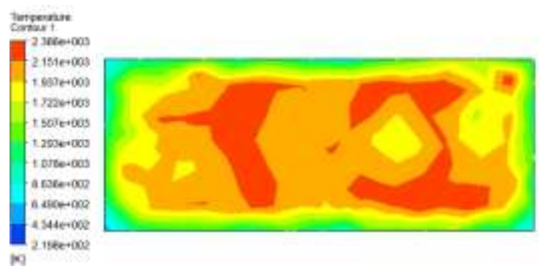
(b) Temperature distribution in chamber for trapezoidal fin at velocity of 0.5m/s



(c) Temperature distribution in chamber for triangular fin at velocity of 0.5m/s



(d) Temperature distribution in chamber for rectangular fin at velocity of 1 m/s



(e) Temperature distribution in chamber for trapezoidal fin at velocity of 1 m/s

Fig. 4: Temperature distribution in chamber for different fins at different velocity

1. Analysis of Average Temperature

In this study, three types of fins were considered viz. rectangular, trapezoidal and triangular. Further, a parametric study was performed for each fins by varying no. of fins, fins thickness and fins length.

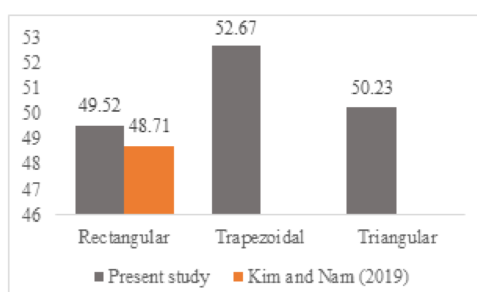


Fig. 5: Comparison of average temperature

IV. CONCLUSION

Three simulation model was developed by changing the shape of fins attach to PV. In this study, three types of fins were considered viz. rectangular, trapezoidal and triangular. Further, a parametric study was performed for each fins.

For triangular fins of different lengths between the study by Kim and Nam (2019) for rectangular fins and the present study for triangular fins. The data includes fins with lengths of 30 mm and 60 mm, and the objective is to calculate the percentage improvement in temperature performance observed in the present study. For fins with a length of 30 mm, Kim and Nam recorded an average temperature of 48.71°C, whereas the present study noted a higher temperature of 51.26°C. For fins with a length of 60 mm, Kim and Nam's study reported an average temperature of 47.65°C, while the present study recorded a temperature of 50.39°C. The average temperatures for triangular fins in the present study are higher compared to those for rectangular fins in Kim and Nam's study. Specifically, the present study shows an increase in temperature of approximately 5.24% for 30 mm fins and 5.75% for 60 mm fins.

For the rectangular fin, the average temperature reported by Kim and Nam (2019) was 48.71°C, while the present study recorded an average temperature of 49.52°C. This represents a percentage improvement of 1.66%, indicating a modest enhancement in thermal performance. The rectangular fin's design adjustments or experimental conditions in the present study likely contributed to this slight increase in temperature efficiency. The trapezoidal fin, for which no previous data from Kim and Nam (2019) is provided, shows an average temperature of 52.67°C in the present study. Using the average temperature for the rectangular fin from Kim and Nam (2019) as a reference, the percentage improvement is calculated to be 8.13%. This significant improvement suggests that the trapezoidal fin design is considerably more effective at heat transfer, likely due to its geometric configuration, which may offer a larger surface area or more favorable heat dissipation characteristics.

Similarly, the triangular fin exhibits an average temperature of 50.23°C in the present study. Again, referencing the rectangular fin's temperature from Kim and Nam (2019), the triangular fin demonstrates a percentage improvement of 3.12%. This indicates a notable enhancement in thermal performance, potentially attributed to the triangular fin's shape, which may facilitate better airflow and more efficient heat transfer.

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