Enhancing a solar panel cooling system using an air heat sink with different fin configurations

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Abstract. The temperature of a solar panel is an important parameter, which influences its performance and efficiency. Thus, development of solar panel cooling systems represents a new face of technology that may be used to improve power generation. Here, the reduction of solar panel temperature using an air-cooled heat sinks is studied numerically. The design of the heat sink comprises rectangular fins and rectangular fins with holes, made from a material with high thermal conductivity. The cooling efficiency is studied for different configurations of the heat sink, which are obtained by changing the fin numbers and hole distances. The numerical model is realized, using ANSYS-Fluent software, for a steady state whereby the ambient temperature is 25–35 °C, for different heat flux values. Increasing the number of fins and holes decreases the panel temperature. The reduction of panel temperature with fins is 50% compared to solar panels without fins.

1. Introduction

The use of renewable energy is becoming more popular, due to an increase in the human population and environmental issues. Solar energy is one of the most important renewable energy sources and thus attractive for researchers.

Solar panels generate power from the sun’s radiation without damaging the environment. The solar panel receives the radiation and converts this to heat. However, extra heat must be dissipated to avoid excessively high temperatures that reduce panel efficiency. Therefore, reducing the effects of extra heat on solar panels has become worthy of research.

The use of a heat sink in the back of the solar panel is one method by which to reduce the panel’s temperature, because the heat sink increases the conventional heat transfer and heat dissipation. Numerous investigations have considered ways to maintain panel temperature within acceptable limits. These include multi-cooling techniques to reduce the heat energy and surface panel temperature [1]. Air-cooling and water-cooling heat sinks made from aluminum have been used experimentally. An increase in output power of 20.96 watts, and an increase in efficiency of not
less than 3%, was achieved, making the module more efficient and productive. Solar panel efficiency was improved by minimizing the high operating temperatures using air heat sinks [2]. The heat sink reduced the temperature of the panel and improved the generation of electricity.

Solar panel performance has also been experimentally discussed using fins, cooling under natural convection [3]. The use of a fin-based cooling system caused the temperature of the solar panel to drop significantly, and the power output of the panel was improved by 5.5% under natural convection. The influence of solar panel inclination, solar radiation, ambient temperature and wind velocity on the performance of solar panels with cooling fins has also been studied [4]. The average electrical efficiency of a panel with fins increased by 1.3% for different panel inclinations, and decreased with increase in the ambient temperature. Wind velocity had a significant effect on the cooling system, which led to better electrical performance. The finned panel efficiency increased by 1.8% compared to panel efficiency without fins, with different wind velocity.

A micro-fin heat sink was created on a solar panel to improve thermal performance [5]. The power output increased by 50%, compared to an un-finned surface. The influence of air velocity on the performance of solar panel has also been studied numerically [6]. The optimum value of velocity which decrease the panel’s temperature was obtained. A thermoelectric cooling module connected to the rear of the solar PV module with an aluminum heat sink was fabricated, to enhance performance [7].

Electrical efficiency can be increased using thermoelectric cooling and the absorbed heat may be used for drying applications. Water cooling of PV panels, to improve the efficiency and reliability of energy conservation, has been tested experimentally [8]. The temperature of the solar panel reduced by 10% compared to the solar panel without water cooling. Elsewhere, a cooling system made of photonic films was investigated to radiate the extra heat [9]. The cooling system was used in a concentrated solar panel to reduce the solar cell temperature effectively. The cooling system was attached to the solar panel and lowered the cell temperature by 5.7 °C, which improved performance.

In this work, a numerical model of cooling solar panel using different configurations of the air-cooled heat sinks is discussed. The heat sink consisted of rectangular fins and rectangular fins with holes, made of a high thermal conductivity material such as copper. The study methodology was applied for different configurations of the heat sink, obtained by changing the fin numbers and hole distances on the fins. The numerical model was realized at different ambient temperature, 25–35 °C, and various heat flux values. The panel’s temperature decreased by 10 °C more than was the case with no fins. The influences of fin size, holes in fins and orientation on the performance of energy production are discussed.

2. Problem statement

Figure 1 shows a schematic design of the considered solar panel geometry and fin configuration. The solar cell consists of a glass layer, a protective glass layer for the solar cell (glass cover) and a protective layer of Tedlar below the solar cell. The solar cell transforms 12–14% of the absorbed solar radiation to electricity, while the remaining heat radiation is transformed into heat dissipated into other components of the solar panel. The dissipated heat will affect the panel components and lead to decreased panel efficiency. Therefore, a cooling system is needed to recover the heat that influences panel component performance.

In addition, in natural convection generally, buoyancy forces cause fluid to move. This creates a thermal boundary layer which starts to develop once the solar radiation hits the glass surface.
However, copper fins disturb the boundary layer’s growth and lead to enhanced natural convection.

To investigate the effect of fins and their modification on heat transfer performance of solar panel, it was necessary to study the number of fins, their spacing, the number of fin holes and the spacing of holes needed to obtain the optimum design. In this study, solar panel of 0.4 m length and 0.1 width were modeled. The properties of the solar panel layers are listed in Table 1. The cooling system used a heat sink made from copper, which had the same dimensions as the panel. The thickness of the sink’s base was 0.02 m and it was attached to the Tedlar layer. The fins were made from copper with the following dimensional characteristics:

![Figure 1](attachment:image.png)

**Figure 1** (a) A schematic of the considered solar panel geometry (b) solar panel with fins configuration (c) solar panel with fins and holes.

| Layer  | Thickness (m) | Thermal conductivity (W/m.K) | Density (kg/m³) | Specific heat (J/kg.K) |
|--------|---------------|------------------------------|-----------------|------------------------|
| Glass  | 0.0032        | 1.8                          | 3000            | 500                    |
| PV cell| 0.0003        | 32                           | 2330            | 677                    |
| Tedlar | 0.0005        | 0.35                         | 960             | 2090                   |
| Copper | 0.02          | 398                          | 8954            | 380                    |

**2.1. Governing equation and boundary conditions**

In this study, a solar panel with fins under natural convection and solar radiation was analyzed. The equation of mass, momentum and energy in the fluid were solved by assuming that the fluid is non-Newtonian. The following system summarizes the governing equations:

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial x} + \frac{\partial w}{\partial x} = 0 \tag{1}
\]

\[
\rho \left( u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial x} + w \frac{\partial u}{\partial x} \right) = \frac{\partial p}{\partial x} + \mu \nabla^2 u \tag{2}
\]
\[ \rho \left( u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = \frac{\partial p}{\partial x} + \mu \nabla^2 u \]  \quad (3)

\[ \rho \left( u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = \frac{\partial p}{\partial x} + \mu \nabla^2 u \]  \quad (4)

\[ \rho \left( u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = \frac{\partial p}{\partial x} + \mu \nabla^2 u \]  \quad (5)

where \( y \) is the direction of the gravity force, \( x \) is the normal direction to the gravity and \( z \) is the direction on the thickness side. The flow velocity in the \( x, y \) and \( z \) directions are assumed by \( u, v \) and \( w \) respectively. Also, the \( \rho, \mu \) and \( \alpha \) are the fluid density, viscosity and thermal diffusivity.

The governing equations were subjected to the following boundary conditions:

\[ \frac{\partial T}{\partial y} = 0 \text{ at } y = 0 \]  \quad (6)

\[ T = T_w \text{ at } y = l \]  \quad (7)

\[ P = P_\infty \text{ at } y = l \]  \quad (8)

The radiation heat transfer from surface can be determined from [10]:

\[ Q_{rad} = \sigma \varepsilon (T_w^4 - T_\infty^4) \]  \quad (10)

where, \( \varepsilon \) is the surface emissivity coefficient, and \( s \) is the Stefan Boltzmann constant equals to \( 5.67 \times 10^8 \text{ W/m}^2\text{. K}^4 \), respectively.

2.2. Numerical modeling validation

To validate the results of the model, the solar panel model was studied under natural convection and solar radiation with 1000 W/m\(^2\) and (25-35) °C of ambient temperature. The dimensions of the investigated solar panel were 120 cm × 54 cm × 3 cm. The solar panel was made from monocrystalline silicon cell. Natural convection was assumed, with the heat transfer coefficient of 10 (W/m\(^2\) K). The solution of the continuity, momentum and energy equation for the system was obtained using Fluent 18. The 3-D model geometry and the mesh were completed, with different refinements for the model and the heat sink where the minimum element size that obtain accurate results was realized. The numerical results match the results reported by [11], as shown in Figure 2.

In this study, the geometry of the model as shown in Figure 3 was realized using a Creo.3 design modeler. Various case studies were analyzed, to study the influence of spacing, holes and space between holes on the performance of the cooling system. The fin thickness was 0.02 mm and the spacing between fins was 0.01 mm. Where 10 holes were created on the fins, the diameter of the hole was 0.015 mm and the gap between them was 0.04 mm. When the number of holes was 20, the gap between the hole reduced to 0.02 mm.

The parameters of case studies are shown in Table 2. The grid independence study was discussed for different element sizes. The normal solar radiation used in the calculation was 800, assuming vertical integration of the panel.
Figure 2 The numerical results for validation.

Figure 3 The geometry of the model.

Table 2 The parameters of case studies.

| Case Number | No. fins | No. holes |
|-------------|----------|-----------|
| 1           | 1        | 10        |
| 2           | 2        | 10        |
| 3           | 3        | 10        |
| 4           | 5        | 10        |
| 5           | 2        | 10        |
| 6           | 3        | 10        |
| 7           | 5        | 10        |
| 8           | 5        | 20        |
3. Results and discussion

3.1 Influence of fins on solar panel cooling performance

The parametric study of a solar panel cooling system was performed, to study the influence of heat sink cooling performance on panel temperature. The study was discussed under natural convection and radiation heat transfer. Different heat sink designs and case studies were achieved where the thickness of fins remained constant.

The temperature distributions of panels in Case 1 to Case 4 are shown in Figure 4, when the heat flux was 800 and the ambient temperature was 27 °C. These cases were tested under the same conditions. The panel temperature fell below the maximum temperature of flat panel that is shown in Figure 4(a). The panel’s temperature with fins was compared with the temperature of a flat panel. The effect of the number of fins upon the panel temperature was noticeable. Increasing the number of fins due to increasing the spacing decreased the panel temperature. The decrease of panel temperature led to increased panel efficiency.

The effects of ambient temperature and radiation heat on the panel temperature are shown in Figure 5. Increasing the number of heat flux and environment temperature increased the panel temperature. Therefore, the cooling system reduced the panel temperature that led to improved panel efficiency. The heat performance of the cooling system depended on the number of fins and spacing between them. Temperature decreased by 12%, compared to the flat panel.
Figure 4  The temperature distributions of panel with and without cooling system (a) panel has no fins (b) panel has two fins (c) panel has three fins (d) panel has five fins.

Figure 5  (a) the maximum temperature of panel without fins (b) the maximum temperature of panel with two fins (c) the maximum temperature of panel with three fins (d) the maximum temperature of panel with five fins.

3.2 Influence of holes between fins

Holes were created on each fin whereby the gap between the holes remained constant and the number of holes was 10 for each fin. The effect of holes on the performance of the finned heat sink was substantial. The thermal performance of the solar panel increased dramatically due to the increased convection heat transfer area. The effect of holes on the finned heat sink for different heat fluxes and ambient temperature is shown in Figure 6. The temperature of this solar panel decreased by 12%, compared to the flat panel.
Figure 6 (a) the maximum temperature of panel has two fins and 10 holes (c) the maximum temperature of panel has three fins and 10 holes (d) the maximum temperature of panel has five fins and 10 holes.

In addition, increasing the holes on the fins in Case 8, which had 5 fins and 10 holes, contributed to a decrease in solar panel temperature which enhanced the performance of that panel. Figure 7 shows the panel with 5 fins and 20 holes at different ambient temperature and heat fluxes. The panel temperature decreased 1 °C when the heat flux was 800 W/m².K, while the decreasing was not noticeable at high heat flux. Therefore, increasing the number of holes slightly affected the panel temperature distributions at high heat flux and ambient temperature.

Figure 7 The maximum temperature of panel with five fins and 20 holes.
4. Conclusions

In this work, the cooling of a solar panel using air-cooled heat sinks with different configurations of fins and holes was studied numerically. The air heat sink contributed to a dramatic reduction in the panel’s temperature. Furthermore, there was improvement in cooling of the heat sink obtained by changing the fin numbers and hole distances on the fins. The panel’s temperature decreased with a decrease in the ambient temperature and the heat flux. Use of the fins and holes reduced the panel temperature, which improved the panel performance. The panel’s temperature with fins reduced by 50% compared to the panel’s temperature without fins.

Recommendations

An experimental study is needed to verify the numerical modeling. Also, the optimum design that reduces the panel’s temperature should be found.

Nomenclatures

| Symbol | Definition          |
|--------|--------------------|
| $u$    | Velocity component in x-direction |
| $v$    | Velocity component in y-direction |
| $w$    | Velocity component in z-direction |
| $\rho$ | Density (kg/m$^3$) |
| $\mu$  | Viscosity (N.m$^2$/s) |
| $T$    | Temperature (°C) |
| $P$    | Pressure (Pas. s) |
| $T_w$  | Wall temperature (°C) |
| $P_\infty$ | Fluid pressure (Pas. s) |
| $Q_{rad}$ | Radiation heat flux (W/m$^2$) |
| $\varepsilon$ | Emissivity |
| $T_\infty$ | Fluid temperature (°C) |

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