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EXPERIMENTAL AND SIMULATION STUDY FOR IMPROVING THE SOLAR CELL EFFICIENCY BY USING ALUMINUM HEAT SINKS

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A B S T R A C T

The research conducted deals with the use of an aluminum heat sink, which is usually used to cool electronic cores and integrated circuits, to cool a solar cell and study the effect of microprocessors and integrated circuits on the performance and temperature of the cell. In this study, an experiment was carried out and simulated using computational fluid dynamics. The results showed that increasing the temperature of the solar cell leads to an accelerated decrease in the open circuit voltage, but when a heat sink is used, the increasing temperature of the cell is reduced more slowly over the same period. Thus, the open circuit voltage drop is reduced more slowly as well, which means the cell operates more efficiently under the same conditions. The temperatures are 290 K at the lowest point and 350 K at the highest point, which shows that heat is being dissipated from the solar cell to the heat sink. It is evident that as the heat sink's number of fins increases, the rate at which heat is transferred increases because the enhanced heat transfer that results from having more fins lowers the heat sink's temperature. These findings can help improve the efficiency of solar power generation and increase the efficiency of solar cells in converting solar energy into electrical energy.

1. INTRODUCTION

The majority of today's energy needs have been met using fossil and non-renewable fuels, but these resources are quickly running out and emitting greenhouse gases. Therefore, to address the existing issues, clean, renewable energy sources are utilized. Among them are solar energy sources, which are thought to produce no industrial waste or carbon dioxide emissions (Majdi et al., 2022). Over time, photovoltaic (PV) panels have been enhanced to more effectively utilize the vast solar resource. However, these panels

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struggle to efficiently transform solar energy into electrical energy, which reduces the efficiency of the photovoltaic (PV) panels and shortens their lifespan (Moria et al., 2020). Numerous elements, including insolation, wind speed, and ambient temperature in the area, have an impact on the temperature of solar cells. Following cell type, there is a shift in cell temperature. Phase change materials (PCMs), which are being developed, can be used to store thermal energy, or active airflow cooling can be used to lower the temperature rise of photovoltaic panels. When compared to approaches without refrigeration, these techniques can boost electric power generation efficiency by up to 9% (Huang et al., 2021).

On this subject, many scholars have recently conducted investigations. In a study by Huang et al., a numerical and experimental PV-PCM system was compared to a familiar air-cooled arrangement (Huang et al., 2018). The researchers found that "RT27" PCM with metal plates is suitable for PV panel temperature rise in a PV-PCM system. In the Hasan et al. study, it was reported that when using PCMs, the PV panel temperature was kept below 40 °C for 6 hours (Hasan et al., 2016). In another study by Biwole, it was shown that the PV-PCM panel can keep the temperature below 40 °C for 80 minutes at a solar radiation of 1000 W/m2 (Bitola et al., 2017). Nehariet's research using numerical simulations using commercial Computational Fluid Dynamics (CFD) code (Fluent 6.3) indicates that the temperature of the PV panel increases with increasing inclination and that small slopes (less than 45 degrees) have good cooling for this panel (Nehari et al., 2017). In another study by Mousavi Baygi and Sadrameli, a photovoltaic cell cold by passive cooling system designed and made using phase change materials, polyethylene glycol 1000, was used in the thermal management study of a PV panel as a PCM (Mousavi Baygi & Sadrameli, 2016; Sudhakar et al., 2014). With the combination of PCM and PV cells, electrical efficiency increased by up to 8% and the temperature of the photovoltaic cell was reduced by 15 °C. Sudhakar et al. may also refer to a study where they presented a photovoltaic cooling method using PCM. In this combined method, the air is cooled by using a thermal energy storage tank containing a closed PCM, and the cold air stream passes through the duct attached to the bottom of the cell to remove the heat. In the daytime cooling process, the PCM phase change material melts and solidifies freely at night and in the early morning hours due to the ambient airflow through the tank. Sardarabadi et al. (2019) performed a study to evaluate the effect of the simultaneous use of zinc oxide/water nanoparticles and paraffin wax as phase change materials in a PVT/PCM system. The photocell was equipped with a metal plane and tubes surrounded by paraffin wax. The study showed that the temperature of the solar panels in the PVT/PCM system decreased by 16 °C and the output power increased by 13%.

As for Huang's study, the performance of the PV panel combined with the PCM and the panel in the cooling system was evaluated. Using the board, a PCM enclosure is attached, and two different PCMs are disconnected from the back of the board to control the board temperature (Huang, 2016). The plates were used to increase the thermal conductivity of the PCM. Two fin shapes (triangular and semicircular) and four different types of PCM (RT21, RT27, RT31, and RT60) were studied. The study showed that the highest plate temperature drop could be obtained by using triangular fins and a PCM of type RT27-RT21. Atkin and Farid (2014) studied the use of an externally finned thermal solution-filled graphite material (PCM) as a viable method for photovoltaic thermoregulation. Four different thermal techniques were used in this study. Namely (1) Case A: PV plate without thermoregulation. (2) Case B: PV plate with phase change material filled on the back surface with a thickness of 30 mm. (3) Case C: PV with a heat sink attached to the rearward surface. (4) Case D: PV plate with an integration of a graphite-infused phase change material and a finned heat sink (Indartono, 2019). The result shows the thickness of 102 m PCM, the power output, and the energy efficiency PV are higher than the reference, i.e., 23.8% and 2.1%, respectively.

The temperature of a solar cell can have a significant impact on its output capacity. This temperature is determined by the cell's encapsulation and the photovoltaic (PV) material used (Kaur & Kumar, 2021; Al-Salaymeh et al., 2021). Environmental factors such as ambient temperature and wind speed and direction can also affect the cell's temperature by increasing the area exposed to air, increasing the airflow over the cell's surface, or both (Shukla et al., 2021). Air-cooling, such as heat sinks, is a typical example of using air-cooling to keep the temperature of electronic systems within permissible limits. Air-cooling is the primary and simplest way to control the temperature of electronic devices, ranging from portable devices to large business systems. Its benefits include accessibility, simplicity, and widespread use. Metals like aluminum and copper have very high thermal conductivities, whereas plastics have very low thermal conductivities (Daud et al., 2021). The aluminum thermal conductivity is around 200 W/m °C, which means that heat can travel about a thousand times faster than in plastic, where the thermal conductivity is about 0.2 W/m °C. Increasing the temperature of a solar cell causes a decrease in the open-circuit voltage, which is the maximum voltage that the cell can produce when not connected to a load. This, in turn, can affect the cell's efficiency, leading to a decrease in its overall performance (Singh et al., 2021). Therefore, it is essential to maintain the temperature of a solar cell within a permissible range to ensure its efficiency and performance.

The first objective of this research is to use the latent heat property of the heat sink to ensure that the temperature of the photovoltaic panel is maintained at a level close to the ambient temperature, which will enhance the efficiency of the photovoltaic cells, increase the power output, and protect the solar cell. The second objective is to examine the accomplishment of a photovoltaic system with a heat sink under real atmospheric conditions to enhance heat exchange and heat removal from the photovoltaic cell. In this research, a heat sink, which is usually used to cool electronic devices and integrated circuits, was used to cool a solar cell. Study the effect of this cooling microprocessor and integrated circuits method on cell temperature and cell performance, and compare the results of the experiment with a CFD software simulation model of the cell with a heat sink. Figure 1 shows the proposed model of the cell with the heat sink.

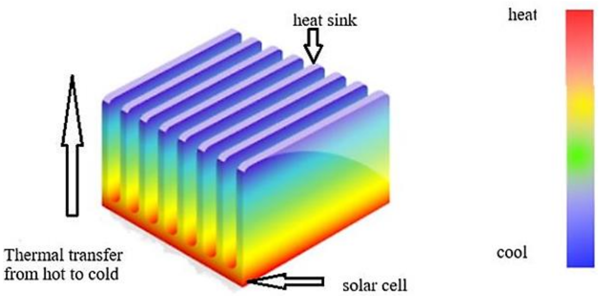

Figure 1. The proposed model of the cell with the heat sink

2. TYPES OF HEAT SINKS

Material heat sinks are designed to efficiently regulate the temperature of electronic or mechanical devices by transferring heat to a coolant or liquid medium. They are made up of an expanded base that is attached to the device's surface and "fins" that serve as an exchanger. Heat sinks are frequently used in computer configurations to cool the CPU, chipsets, GPUs, and RAM, enabling the system to operate at peak efficiency without overheating and resulting in lag or irreparable harm. This is accomplished by supplying adequate airflow for temperature control. Materials like aluminum and copper alloys are used to make heat sinks (Quill et al., 2018).

The high thermal conductivity of aluminum heat sinks, which is estimated at 235 W/m.K, makes them widely employed. This metal is one of the most commonly utilized on Earth for heat sink applications due to its outstanding thermal conductivity. With strong heat transfer strength and machine performance, its low density also makes it perfect for use in connecting machines. Despite having excellent corrosion resistance, aluminum is not as sturdy as brass. It is, however, a very recyclable material, making it a green choice.

Copper heat sinks are frequently used due to their high conductivity (around 400 W/mK), corrosion resistance, and antibacterial qualities. However, depending on its purity, copper can be expensive and difficult to manufacture. Copper alloys are often used in industrial applications, such as power plants, solar energy systems, and dams, due to their high cost. Heat sinks come in many types of construction designs for computer and electrical motherboards. Both aluminum and copper heat sinks come in these shapes (Razeeb et al., 2018):

- Extruded heat sinks
- Bonded heat sinks
- Forged heat sinks
- Sealed heat sinks
- CNC machining heat sink
- Zipper fin heat sinks

Figure 2. Different types of heat sinks

3. TYPES OF HEAT SINKS

It is known that the open-circuit voltage in the solar cell decreases with an increase in the cell's temperature. It is also affected by the intensity of solar radiation, as it is a function of the solar cell temperature and intensity of solar radiation.

$$V_{OC} = f(S, T_C) \tag{1}$$

In order to measure the temperature of the solar cell, the temperature is taken from the average temperature of the upper surface of the cell and the temperature of the lower surface, where the equation is:

$$T_C = T_{av} = (T_{top} + T_{bottom})/2 \tag{2}$$

Several mathematical equations can be used to simulate a solar cell with an aluminum heat sink, among them:

1- The equation for the electrical energy generated by the solar cell:

$$P = V \times I \tag{3}$$

2- The equation for the total efficiency of the solar cell:

$$\eta = P/Pin \tag{4}$$

3- The heat transfer equation between a solar cell and an aluminum heat sink:

$$Q = h \times A \times (T_C - T_a) \tag{5}$$

4- The heat transfer equation between the heat sink and the surrounding environment:

$$Q = h \times A \times (T_a - T_e) \quad (6)$$

5- Equation of the electrical energy generated by the solar cell based on the solar radiation received:

$$P = \eta \times A \times G \quad (7)$$

6- The equation for the thermal difference between the solar cell and the heat sink:

$$\Delta T = (P \times R_s + Q) / (I_{SC} \times (\alpha + \beta \times V_{OC})) \quad (8)$$

In this research, the temperature of the bottom surface was adopted to represent the solar cell temperature; where it was placed, the thermal sensor was directly on the lower surface of the cell. It did not place the sensor on the upper surface due to the presence of the heat source opposite the surface. As the reading of this sensor will be a result of its heat from the thermal optical source, which will not represent the temperature of the upper surface of the solar cell, the heat sink used is a piece of metal designed in a certain way that is placed on the surfaces of the electronic elements. Where it transfers heat from the electronic element to the heat sink and then to the outside air surrounding the heat sink. The greater the rate at which heat transfers from the surface of the electronic element to the heat sink, the greater the cooling efficiency. In order for this to happen, both the surface of the electronic element and the base of the scatter must be in full contact. The larger the heat sink, the more heat is absorbed and distributed to it. The efficiency of heat transfers from the electronic component (solar cell) to the heat sink and to the outside air depends on the metal the heat sink is made of. The type of metal from which the disperser is made and the intensity of polishing its base in contact with the solar cell play an important role in heat transfer from the cell to the disperser and from it to the outside environment. It is known that metals differ among themselves in terms of their ability to transfer heat, and among the metals widely used in the manufacture of dispersants are aluminum, copper, and silver. In our research, we used aluminum, which is the most widespread and widely used due to its low price, abundant availability, lightweight, and ease of formation. The thermal conductivity of aluminum is 235 W/mK (Quill et al., 2018).

3.1 Experiment and measurements

In this research, a silicon solar cell with a circular shape with a diameter of 10 cm and a thickness of 0.3 cm was used and installed on a heat sink. in the presence of an electric light source in front of the solar cell with a power of 500 watts and directly representing a light and heat source at the same time. In order to gradually raise the temperature of the solar cell under study and for the purpose of measuring the temperature of the cell, a thermal sensor was attached to the lower surface, and the temperature of the type k-thermocouple of the solar cell was monitored. (90 cm) the external environment by placing a device to measure the temperature by installing a thermometer at a distance from the solar cell and connecting the two ends of the solar cell to a voltmeter in order to record the open circuit voltage. The measurement steps were as follows:

To conduct this experiment, the open circuit voltage Voc and the temperature of the bottom surface of the cell were recorded every two minutes for a period of 20 minutes, starting from the moment the light source was turned on. This data was recorded in Table (1). A specially manufactured heat sink was used to cool the processors in the computer during the experiment. It was shaped to match the shape of the solar cell used in the research and to keep the sensor in the same position as before, during the first stage of measurements (without the sink). To ensure better heat transfer and eliminate voids between the lower surface of the cell and the upper surface of the heat sink, the thermal paste was applied to the lower surface of the solar cell. During the experiment, the open circuit voltage Voc and the temperature of the bottom surface of the cell were recorded, just as they were in the case of the cell without a heat sink. The results of this experiment are shown in Table (2). Figure 3 illustrates the solar cell installed on the heat sink.

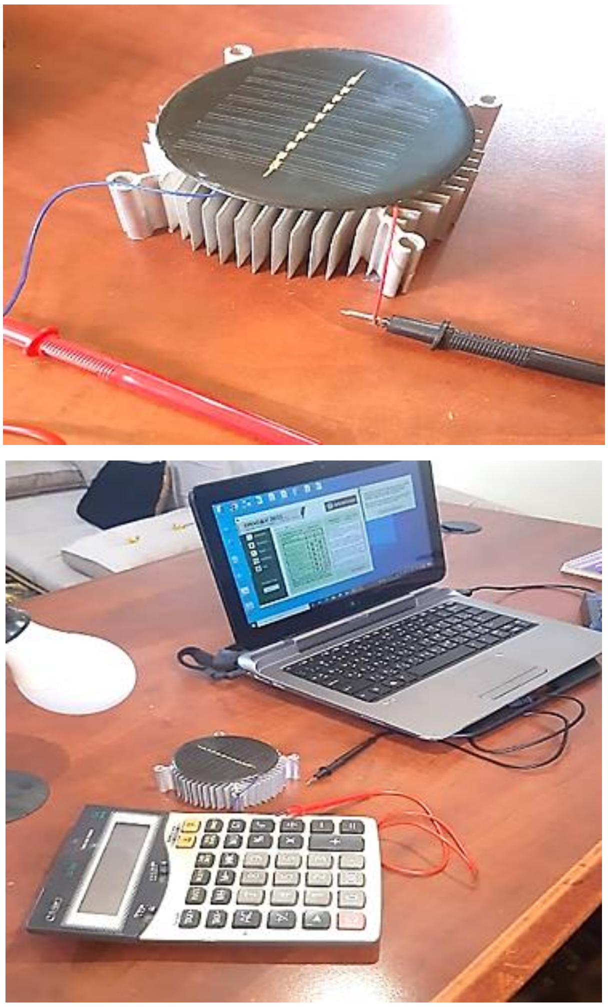

Figure 3. The solar cell with a heat sink

Table 1. Variation of temperature and open circuit voltages with time without a heat sink

Time (min)	Open circuit voltage (V)	Temperature (°C)
2	6.4	8
6	6.23	14
8	6.15	21
10	6.10	27
12	5.95	29
14	5.85	33
16	5.75	34
18	5.72	36
20	5.70	38

Table 2. Variation of temperature and open circuit voltages with time and a heat sink

Time (min)	Open circuit voltage (V)	Temperature (°C)
2	6.65	8
6	6.56	12
8	6.51	14
10	6.45	17
12	6.40	18
14	6.40	18.2
16	6.35	18.4
18	6.30	20
20	6.25	20.5

3.2 Simulation CFD

CFD software can be used to analyze heat flux, kinetic movements, and chemical reactions within a solar cell equipped with a heat sink. This is done by entering data about dimensions, materials used in the cell and heat sink, heat flow rates, and internal temperatures for each part of the cell. If a simulation was carried out in the CFD program of a circular solar cell with a diameter of 10 cm and an aluminum heat sink with a fixed solar radiation value of 500 W/m2, the temperatures were determined in all areas of the solar cell and the heat sink, and the temperature distribution was better. The design of the heat sink and the temperature distribution inside the solar cell may both be optimized using the findings of the CFD simulations, which will lead to improved cell efficiency and performance. As a result, it will be possible to make greater use of solar energy and cut the price of using solar cells to generate power. Users of computational fluid dynamics can look at the properties of fluid flow and heat transport in a specific area. Data input for CFD analytics is required for parameters including geometry, mesh, and setup. The CFD function can be used to generate and compare outcomes once the input data has been processed. To perform CFD modeling, data on the dimensions and specifications of the system must be entered, including the size of the solar cell, heat sink, type of material, number of fins, and the basic design dimensions as shown in Figure 4. Geometry and mesh of the cell and heat sink

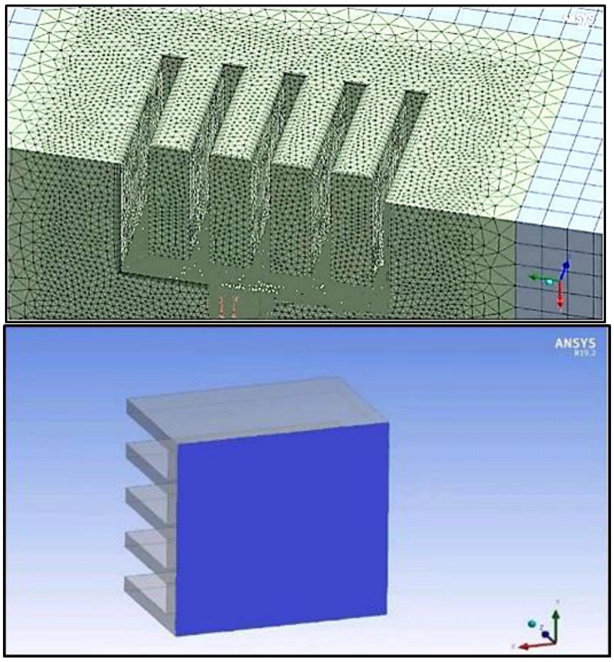

Figure 4. Geometry and mesh of the cell and heat sink

4. RESULTS AND DISCUSSION

After 30 iterations, the distributor solution has converged, as depicted in Figure 5, which shows the temperature contour. The minimum temperature recorded is 290 K, while the maximum temperature is 350 K, indicating the dissipation of heat from the solar cell to the heat sink.

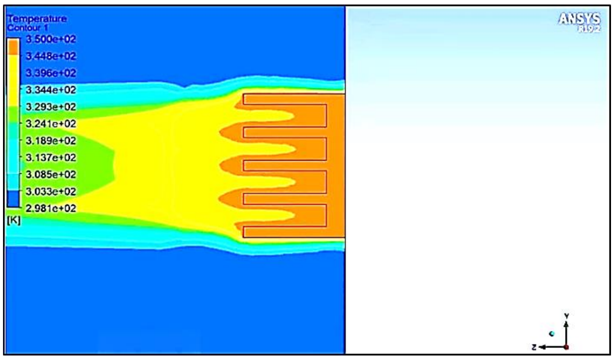

Figure 5. Temperature contour of the solar cell with heat sink

The velocity vector of all 54 channels at a specific (x, y, z) location, which is located in the middle of the small fins in the distributor, is depicted in Figure 6. This plot illustrates the uniformity of the velocity vector along the heat sink, and the regularity of the plot indicates the uniformity of heat transfer in each solar cell as well as throughout the entire body of the heat sink.

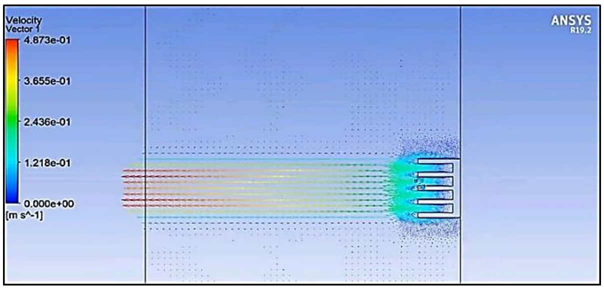

Figure 6. The velocity vector along the heat sink

Another advantage of having a velocity vs. position chart is making sure the CFD calculation is correct and the software has set the heat sink as a solid while realizing that air is moving around the fins.

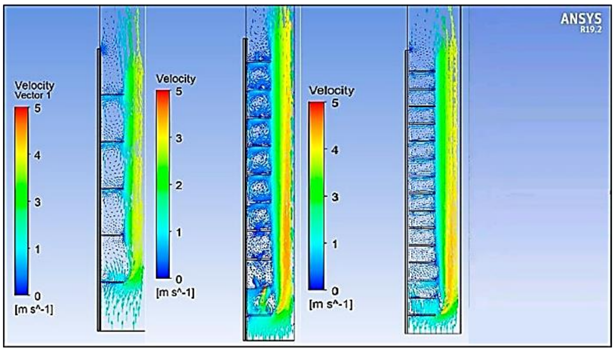

Figure 7. Heat transfer rate of the solar cells with different fins number of heat sink

Figure 7 shows the heat transfer rate from the solar cells to the heat sink. The results are shown for three different fin numbers of the heat sink, each containing a different number of fins. The horizontal axis in the diagram represents the number of fins in the heat sink, where the number is increased from 5 to 15 fins. The vertical axis represents the heat transfer rate in m/s, and this rate is measured depending on the temperature variation between the solar cells and the heat sink. It can be seen that the heat transfer rate increases with the increase in the number of fins in the heat sink, as the heat distribution is improved on the heat sink with more fins, and thus the temperature of the heat sink is reduced. This can improve the efficiency of converting solar energy into electrical energy by the solar cell.

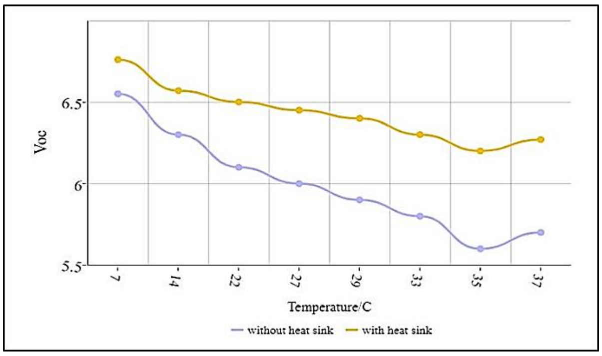

Figure 8. The potential difference of solar cells with temperature, with and without heat sink

Figure 8 shows the variation of the potential difference of solar cells with temperature in two cases, one with the use of a heat sink and the other without a heat sink. It is clear from the figure that the potential difference changes greatly with the temperature of the solar cell. If a heat sink is used, the temperature rise of the solar cell is reduced, and thus the effect of temperature on the potential difference is reduced. This is shown by the orange curve in the figure. In the event that a heat sink is not used, the temperature of the solar cell rises further, which leads to a significant change in the voltage difference, as is evident from the blue curve in the figure.

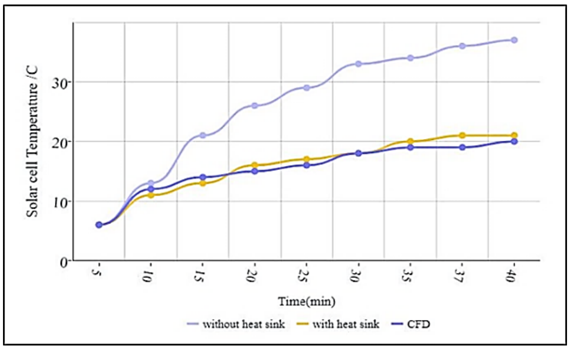

Figure 9. A comparison of the solar cell temperature with time changes for three different cases

Figure 9 shows a comparison of the temperature of a solar cell with time change for three different cases. The first case is the solar cell with a heat sink; the second case is the solar cell without a heat sink; and the third case is the CFD simulation results of the solar cell. It is clear from the curves in the figure that the use of a heat sink reduces the temperature of the solar cell compared to the case in which there is no heat sink. It is also noted that the temperature of the solar cell in the case where a heat sink is used is better controlled and is less fluctuating with time, which leads to an improvement in the efficiency of the solar cell. As for the results simulated by CFD, this tool is used to analyze heat fluxes, liquids, and gases in solar cells. It is clear from the curves that the simulated results are in good agreement with the actual results for solar cells that use a heat sink and those that do not have a heat sink.

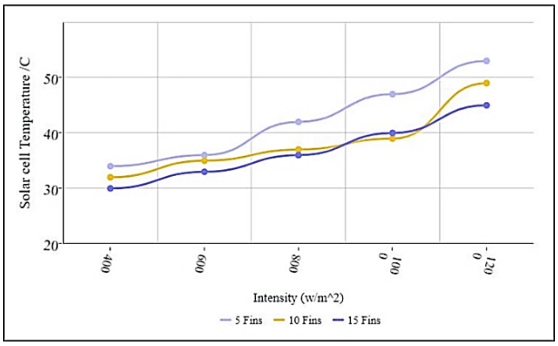

Figure 10. The variation of solar cell temperature with intensity for different No. fins of a heat sink

Figure 10 shows the variation of solar cell temperature with intensity for different numbers of fins on a heat sink. The blue line represents the curve that occurs when a heat sink of five fins is used; the second case is a heat sink of ten fins; and the third case is a fin heat sink. It is clear from the curves in the figure that the heat sink with fifteen fins leads to a better reduction of the temperature of the solar cell compared to a heat sink with ten fins and five fins, especially when the intensity of solar radiation is high. This is because increasing the surface area exposed to heat exchange with the air increases the number of blades in the heat sink. It is also noted that the effect of the number of blades in the heat sink is more evident when the intensity of solar radiation is high, as a greater amount of heat is generated in the solar cell. The influence of the number of feathers is less noticeable when the solar radiation intensity is low, but it still has an impact on the solar cell's temperature.

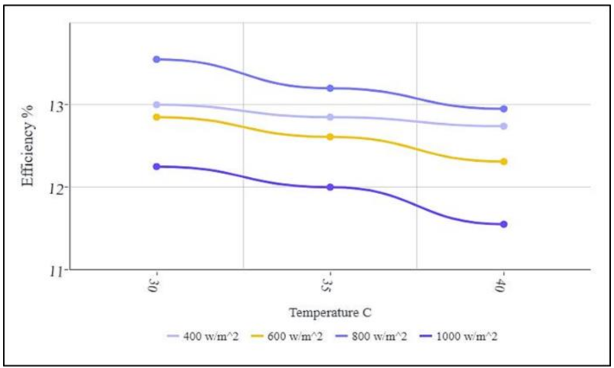

Figure 10. Effect of solar cell temperature and solar radiation intensity on the overall efficiency of the solar cell

Figure 11 depicts how solar cell temperature and solar radiation intensity affect the solar cell's overall efficiency. Each of the four curves in the illustration represents a different level of solar radiation intensity (400, 600, 800, and 1000 watts/m2). The curve that happens when the solar cell temperature is 30 °C is shown by the red line, while the curve that happens when the solar cell temperature is 40 °C is shown by the blue line. The curves show that when the temperature of the solar cell increases, the efficiency of the solar cell drops, and vice versa. Additionally, it mentions that high solar radiation intensities increase the efficiency of solar cells. In general, it can be claimed that the solar cell's temperature has a significant impact on how effective it is. The solar cell can handle more solar radiation better and attain higher efficiency when the level of solar radiation increases.

4. CONCLUSIONS

In this essay, we have discussed solar cells and the value of using them as a sustainable and clean energy source. Along with the parameters that affect the effectiveness of the solar cell, such as temperature and the intensity of solar radiation, the many types of solar cells and how they function were discussed. When compared to ordinary solar cells, the performance of research and studies on the creation of solar cells with heat sinks was reviewed. The results showed that solar cells equipped with a heat sink achieve higher efficiency at high temperatures. This technology increases the efficiency of solar cells and reduces the negative impact of heat on their performance, which helps achieve better performance of solar cells and increase their efficiency. In general, it can be said that the use of solar cells as a renewable and clean energy source is a sustainable and environmentally friendly solution, and they can be used in various vital and industrial applications. Solar cell performance can also be improved by using techniques such as heat sinks and analyzing the temperature distribution inside solar cells using CFD models. Based on the results presented in this research, we expect that interest in improving the performance of solar cells and their development will continue in the future, which will lead to an increase in the use of renewable and clean energy and an improvement in the quality of life in various parts of the world.

NOMENCLATURE

S Solar radiation (w/m^2)
V Voltage (volts)
P Electrical power generated (W)
I Current (A)
Q Heat transferred
T_e Ambient temperature (°C)
ΔT Difference between the temperature (°C)
R_S Internal resistance of the solar cell (ohms)
Q Heat transferred in watts
I_{SC} Short circuit current (A)
α , β Solar cell temperature constants
V_{OC} Critical voltage (volts)
h Heat transfer coefficient (watts/ m^2. k)
A Heat exchange area (m^2)
T_C The solar cell temperature of (°C)
T_a The heat sink temperature of (°C)
G Solar radiation (watts/m^2)
η Total Efficiency (%)

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