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Mathematical Model to Investigate the Temperature Distribution for Photovoltaic Panels

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Abstract

A Mathematical model that has been developed for direct simulation the spatial and temporal temperature profile within the photovoltaic(PV) panel by resolving the unsteady state heat equation in three dimensions, utilizing the method of explicit finite difference to minimize the errors of solution. This model includes the materials composition of PV panel, by affecting their optical and thermal properties when irradiated directly to sunlight. The different temperature across the top and back of panel cell is found a 24.091 °C. The PV adequacy of solar cell is inversely proportional to its temperature of operating at the rear surface of PV cell. This powering temperature is disciple onto desegregates conditions of atmospheric, impacts of panel materials behavior and mounting structure. The coefficient of a free convection heat loss at the rear surface of the cell is as well specified. This analysis indicates the convection heat loss coefficient effect on operating temperature of PV panel, and its efficiency.

Keywords: Photovoltaic Panels, Thermal model, Solar irradiation, Temperature distribution.

Nomenclature

LATIN SYMBOLS	
A	Absorptivity
B_i	Biot number $(h.\Delta z\ k_{eq}^{-1})$
g	Gravity (m/s^2)
Gr	Grashof number $(g\ \beta\ (T_w - T_\infty)x^3/\nu^2)$
h	Heat transfer coefficient $(W.m^{-2}\ {}^oC^{-1})$
I	Power intensity $(W.m^{-2})$
$k_{eq.}$	(PV) materials thermal conductivity $(W.m^{-1}\ {}^oC^{-1})$
k_{air}	Thermal conductivity of air $(W.m^{-1}\ {}^oC^{-1})$
L	length of panel (m)
$\overline{Nu}$	Nusselt number (h x/k)
Q	Heat generation $(W.m^{-3})$
R	Reflectivity
Ra	Rayleigh number (Gr.Pr)
T	Time (Sec.)
T	Temperature (°C)
T_{bc}	PV cell temperature of back (°C)
T_f	Film temperature (°C)
T_∞	Surrounding temperature (°C)
T_{ref}	References temperature (°C)
x, y , z	Distances (m).
GREEK SYMBOLS	
β	Volumetric thermal expansion (T^{-1})
A	Thermal diffusivity of (PV) material $(m^2\ s^{-1})$
δ	Absorption coefficient
ν	Kinematic viscosity $(m^2\ s^{-1})$
ζ	(PV) cell efficiency
ζ_{ref}	(PV) cell Reference efficiency
Δx, Δy, Δz	Increment in the distance (m)
Δt	Increment in the time (sec)
λ	Convergence
θ	Inclination Angle from vertical (degree)
ABBREVIATIONS	
PV	Photovoltaic

1. Introduction

The solar panel execution is mainly subordinate on its Photovoltaic competence. Obviously an elegant PV competence palliates the utilize of solar technique to displace fossil fuels as the essential resource of power. The PV technology is the most popular way of converting solar energy to electricity directly by utilizing solar cells. Approaching solar radiation is absorbed by a semiconductor engrossing material that produces electron-opening pair versatile charge bearers in charge of an electric flow. PV gadgets are arranged by the kind of light retaining materials, thickness of the engrossing material and use of the PV. The working temperature of PV panel is attached to numerous administrators, wind speed, solar radiation, and direction, ambient temperature, composition of panel materials, and the structure of bearing. For idealistic business PV cell, a segment of the heliacal is changed into power, ordinarily 0.13-0.2 and the residuum is changed to warmth [1].

Thermal analysis in the finite element of a PV module under operation was used. At solar irradiation of 10^3 Wm^{-2}, the highest temperature of the cell is 66 ^oC, taking into counting both heat and optical losses. At the temperature of 25 ^oC, the relating PV efficiency is 0.122 matched to 0.15. Likewise, the temperature variance between the pane and rear sheet is slender because of the layers being elevated. PV laminate is mounted into the aluminum body, furthermore it is helpful in cooling overlay along the borders. Inevitably, the array extent for the panel system is significant in deciding the modulus of the efficient convective loss, which would thusly involve the solar cells temperature, and its efficiency [2]. A method of modeling and emulation photovoltaic module that performed in Simulink/Matlab was qualified. It is requisite to predefine a circuit-based emulation model for a PV cell so as to permit the interplay with a converter of power. Characteristics of PV cell that is affected by temperature and irradiation are modeled by a circuit model. A simplified PV valent circuit with a diode valent is utilized as a model. The emulation outcomes are contrasted with disaccord kinds of PV module data sheets. Its outcomes showed that the formed imitation blocks in Simulink/Matlab are identical to factual PV modules, convenient to various kinds of PV module [3]. The influence of PV panel temperature on its parameters out of simulation software and outdoors experimental was reported. The ecological factors effects like solar irradiance and ambient temperature as well were examined so as to inspect their effect on temperature and output execution of PV panel. Throughout simulation and experimental, there is mightily showed that temperature of PV panel plays a decisive part in a production of output power. Both methods exhibit that the most important varied by temperature was output voltage which decreases with the towering PV panel. Reduction of temperatures in output voltage causes the production output power of PV panel cannot be generated efficiency even there are raised of the produced current. Moreover, the fineness operation of PV panel also lowering with the rising of the PV panel temperatures [4]. It has been shown that the effectiveness of PV modules corresponding contrarily with operating temperature. A three-dimensional finite element analysis was used to respect the solar cell temperature. Then, the changes in power generation efficiency were demonstrated. That means the electricity generation diminishes by 0.45 when working temperature ascends by 1^oC [5]. The performance of solar cell decrements with incrementing temperature, essentially owing to raised internal conveyor rates of recombination, triggered by raised conveyor condensations. The operative temperature assumes an important function in the photovoltaic procedure of transformation. Both the power output and the electrical efficiency of photovoltaic module rely straightly on the temperature of working. The electrical execution is for the most part affected by a material of PV utilized. In general, the rendition ratio reduces with latitude on account of temperature. Nonetheless, districts with high elevation have maximal rendition ratio due to low temperature. PV modules with minimal sensibility to temperature are favored for the faint temperature zones and additionally responding to temperature will be further agent in the discouraged temperature zones. The geographic allocation of PV power potential reputing the impact of ambient temperature, and irradiation on PV system rendition is regarded [6].

It can be deduced that the most of the authors are modeled the temperature distribution of the PV panel domain by multiply the value of solar irradiation in different parameters factor in order to represent how the solar irradiation heated the material of PV. They do not dependent upon the fundamentals and principles of the incident radiation falls on the material. In the present research, the rules were depended as one part reflected, and the other part absorbed by surface of material as assuming an opaque material. Then, the absorption radiation was interacted with the particles of material and produces heat as conduction mode with heat generation.

In the current study, the transient thermal model in three-dimensions is predicted to explain the effect of variation solar cell temperature distribution under the average value of sunlight intensity by using a finite difference method with explicit technique. In the simulation program the optical properties for absorptivity, transmissivity, and reflectivity of materials of PV panel are utilized.

2. Mathematical Model

When radiation of sunlight impinges on a PV panel target part of it is reflected and part is absorbed and penetration the materials by thermal conduction. Heat equation has been used to describe conduction with a material of a PV panel irradiated with solar radiation of 945 W/m^2. This is the average values of measuring solar irradiation by the data logging power meter (TES 132) through 2 hours' time, from 11 a.m. to 1 p.m. on 8/3/2018 in the Hillah city, Iraq. The interaction of solar radiation with the panel materials is often described by means of the thermal model, which assumes conversion of solar radiation into heat at the absorbing region of the panel materials. Thus, the distributing of temperature as a function of time at various locations in the bulk of the panel materials was calculated. A three-dimensional heat equation for solid panel materials is used to predict the spatial and temporal temperatures distribution through the PV domain under penetrating solar radiation [7]:

$$\frac{\partial}{\partial x}\left(\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{\partial T}{\partial z}\right)+\frac{Q}{k_{eq.}}=\frac{1}{\alpha}\frac{\partial T}{\partial t} \quad (1)$$

The proportion of incident solar radiation which penetrates the material surface is absorptivity, and is a further factor controlling the quantity of energy transmitted to the panel materials. The term of heating Q in the conduction equation can, so, be written as expressed by ref. [8] as:

$$Q = AI\delta\, exp(-\delta z) \quad (2)$$

Where Q is the source term (heat producing per unit volume per unit time) and it describes the absorption process. A is the absorptivity by A= (1-R), where R is the reflectivity. z is the depth of solar light penetration of intensity I of solar radiation. δ is the absorption coefficient, which is, in general, a function of wavelength and temperature.

A new assumption has been made in the present analysis, that the absorption does not occur in z-direction only, but in three directions, i.e. in x, y, and z coordinates. Therefore, equation (2) can be written as:

$$Q = (1-R)I\delta\, exp(-\delta\sqrt{x^2+y^2+z^2}\,) \quad (3)$$

The spatial and temporal temperature distribution of materials panel is calculated at time intervals of 60 seconds. A finite-difference method with explicit technique has been used to give more realistic, three dimensional description of the temperature response induced by the solar radiation within the materials of a panel. The principles of stability analysis with the numerical scheme are discussed by ref. [9], where $\lambda = \frac{\alpha \Delta t}{\Delta x^2}$ is the convergence factor and assuming $\Delta x=\Delta y=\Delta z=1$ mm. Equation (1) can be written in finite difference form with explicit technique as:

$$T_{i,j,k}^{n+1} = \lambda\, T_{i+1,j,k}^{n} + (1-6\lambda)T_{i,j,k}^{n} + \lambda T_{i-1,j,k}^{n} + \lambda T_{i,j+1,k}^{n} + \lambda T_{i,j-1,k}^{n} + \lambda T_{i,j,k+1}^{n}$$
$$+\lambda T_{i,j,k-1}^{n} + \frac{Q_{(x,y,z,t)}}{k_{eq.}}\alpha\Delta t \quad (4)$$

The number of assumptions and simplification has to be made in order to solve the mathematical model:

1- PV panel with dimensions (644 mm × 540 mm × 6 mm) assumed as a flat plate as illustrated in figure (1- (a)).
2- It has been assumed a symmetrical about x and z axis.
3- The initial condition T(x, y, z, 0) = 25 ^oC, and boundary conditions assumptions as:
a) At the left and right surface through y-axis were impermeable (i.e. adiabatic).
b) At T(x, 0, 6, t) $-k_{eq}\frac{\partial T}{\partial x} = h(T_{bc} - T_\infty)$ as shown in figure (1-(b)).
4- Assume there is no wind effect on the rear surface, then the heat losses from the rear of panel by free convection at the ambient temperature 25 ^oC.
5- The number of nodes (L, M, N) are (645 × 541 × 7). A model predicts the temperatures distribution through PV panel planes, thickness, and the back surface.

2.1. Numerical Analysis

The computer program was designed to simulate the temperature profiles with time at top, front, and side of PV panel domain. Fig. 1-(b) illustrated these planes.

a) At point (a) where x = y = 0; upon the boundary conditions were assumed as shown in figure (1-(b)), then equation (3) becomes:

$$T_{i,j,k}^{n+1} = 4\lambda T_{i+1,j,k}^{n} + (1-6\lambda)T_{i,j,k}^{n} + 2\lambda T_{i,j,k+1}^{n} + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (5)$$

b) Through x-y (top surface)

$$T_{i,j,k}^{n+1} = \lambda T_{i+1,j,k}^{n} + (1-6\lambda)T_{i,j,k}^{n} + \lambda T_{i-1,j,k}^{n} + \lambda T_{i,j+1,k}^{n} + \lambda T_{i,j-1,k}^{n} + 2\lambda T_{i,j,k+1}^{n} + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (6)$$

c) Through y-z plane (side surface)

$$T_{i,j,k}^{n+1} = 2\lambda T_{i+1,j,k}^{n} + (1-6\lambda)T_{i,j,k}^{n} + \lambda T_{i,j+1,k}^{n} + \lambda T_{i,j-1,k}^{n} + \lambda T_{i,j,k+1}^{n} + \lambda T_{i,j,k-1}^{n} + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (7)$$

d) Through x-z plane (front surface)

- Through x-axis (ad)

$$T_{i,j,k}^{n+1} = \lambda T_{i+1,j,k}^{n} + (1-6\lambda)T_{i,j,k}^{n} + \lambda T_{i-1,j,k}^{n} + 2\lambda T_{i,j+1,k}^{n} + 2\lambda T_{i,j,k+1}^{n} + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (8)$$

- Through z-axis (ab)

$$T_{i,j,k}^{n+1} = 4\lambda T_{i+1,j,k}^{n} + (1-6\lambda)T_{i,j,k}^{n} + \lambda T_{i,j,k+1}^{n} + \lambda T_{i,j,k-1}^{n} + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (9)$$

- x-z plane

$$T_{i,j,k}^{n+1} = \lambda T_{i+1,j,k}^{n} + (1-6\lambda)T_{i,j,k}^{n} + \lambda T_{i-1,j+1,k}^{n} + 2\lambda T_{i,j+1,k}^{n} + \lambda T_{i,j,k+1}^{n} + \lambda T_{i,j,k-1}^{n} + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (10)$$

- Right wall of the x-z plane line (cd). This is on the boundary condition, and assumed adiabatic, energy balance should be done through it, so the result is

$$T_{i,j,k}^{n+1} = 2\lambda T_{i-1,j,k}^{n} + (1-4\lambda)T_{i,j,k}^{n} + \lambda T_{i,j+1,k}^{n} + \lambda T_{i,j-1,k}^{n} + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (11)$$

- Corner (b)

$$T_{i,j,k}^{n+1} = 4\lambda T_{i+1,j,k}^{n} + (1-6\lambda-2\lambda B_i)T_{i,j,k}^{n} + 2\lambda T_{i,j,k-1}^{n} + 2\lambda B_i T_\infty + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (12)$$

-Through the rear surface line (bc) as shown in figure (1-(b)). This line on the boundary, conduction = convection $(-k_{eq.}\frac{\partial T}{\partial z} = h(T_{bc} - T_\infty))$.

$$T_{i,j,k}^{n+1} = \lambda T_{i+1,j,k}^{n} + (1-4\lambda-2\lambda B_i)T_{i,j,k}^{n} + \lambda T_{i-1,j,k}^{n} + 2\lambda T_{i,j,k-1}^{n} + 2\lambda B_i T_\infty + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (13)$$

- Corner (c)

$$T_{i,j,k}^{n+1} = 2\lambda T_{i-1,j,k}^{n} + (1-4\lambda-2\lambda B_i)T_{i,j,k}^{n} + 2\lambda T_{i,j,k-1}^{n} + 2\lambda B_i T_\infty + \frac{Q}{k_{eq.}}\alpha\Delta t \quad (14)$$

This set of equations permits to solve the problems of three-dimensional thermal analysis of temperature distribution through PV panel by using explicit finite difference approach.

3. Structure of Photovoltaic Solar Panel

The photovoltaic solar cells realization in this work is the polycrystalline silicon. It is formed of a set of diverse layers of material with various physical properties. It is formed by a different layers:

1. Glass coverage: the glass utilized in PV panel is extremely-clear, with a peak rate of transmittance.

2. Anti-Reflective creosote (ARC) : silicon can reflects up to 0.35 of the approaching radiating. To revoke this , an (ARC) is utilized (silicon nitride), which path the coming photons into the minimal layers of the cell.
3. Photovoltaic PV cells : polycrystalline silicon flake is utilized in the cell.
4. EVA layer : the PV cell is enveloped in a layer of ethylene vinyl acetate (EVA) to stick the panels to the pane of cover and the rear enveloping substance and to a stock electrical deposition and impedance of moisture.
5. Contact of rear metal: entire metal request is made on the adverse side of the PV panels by screen-printing a metal glue, commonly aluminum, onto the rear cell surface.
6. Layer of tedlar polymer: the polymer layer in the PV panel is crafted of polyvinyl fluoride (PVF). This strata is photo firm and supplies more moisture reservation and insulation for the PV layers. These layers are subsumed in a metal bound. The thermal conductivity, thickness, heat capacity, density, and optical properties of every layer are itemized [10].

4. Loss of Heat from the Rear PV cell Surface

At the posterior surface of the panel, the loss of convective heat is demonstrated. Free convection heat loss turns into more important if there is no wind or very little on days of the test. The PV panel was assumed inclined flat plate.

Natural convection from the base of warmed inclination plate for the whole area of Rayleigh number, is specified as a role of the Nusselt number ($\overline{Nu}$), which was reported by ref. [11] as:

$$\overline{Nu} = \left[0.825 + \frac{0.387\, Ra^{\frac{1}{6}}}{\left[1+(0.492/Pr)^{\frac{9}{16}}\right]^{\frac{8}{27}}}\right]^2 \qquad (15)$$

The Nusselt number was calculated depending upon Rayleigh number, and Prandtl number. Then, Rayleigh number (Ra) definable as:

$$Ra = (Gr\ Pr) \qquad (16)$$

Where Grashof number (Gr) of inclined plate is represented as:

$$Gr = \frac{g \cos\theta\ \beta\ (T_{bc} - T_{\infty}) L^3}{\nu^2} \qquad (17)$$

previous equation was derived for the vertical plate but may be readily suitable for plate tilted at the angle over to 60° by substituting (g) with (g cosθ), (θ) is the inclination angle from the vertical. For 0 < θ < 60° . Prandtl number (Pr) is estimated as:

$$Pr = \frac{\nu}{\alpha} \qquad (18)$$

β is the coefficient of volumetric of a thermal expanding which is estimated at the film temperature T_f , and it is definable as:

$$T_f = \frac{T_{bc} + T_{\infty}}{2} \qquad (19)$$

The prominence of natural convective of the heat wastage from the back surface of a solar cell is computed by equation (15). The heat transfer coefficient (h) is calculated as:

$$\overline{Nu} = \frac{hL}{k_{air}} \qquad (20)$$

Where $h = \frac{\overline{Nu}\, k_{air}}{L}$ (21)

The value of the convective heat interchange is proportionate to the variance of temperature amidst the rear plane of the PV cell and the am[illegible]

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The obstetrics effectiveness of the P[illegible] cells is contrarily proportionate to their working temperature. The obstetrics productivity of PV cells portrays by ref. [12] as:

$$\zeta = \zeta_{ref}\left[1 - \beta\left(T_{bc} - T_{ref}\right)\right] \qquad (22)$$

Where ζ_{ref} is the generation efficiency at the reference temperature which takes as 25 °C. This value is about 0.168, and the amount of β is subordinate to the material of the PV cells and it is 0.0045 $^{o}C^{-1}$ for crystalline silicon as reported by ref. [13].

5. Results and Discussion

Figure (2) demonstrates the isothermal contour of the temperature distribution through the top surface (x-y) plane of the PV panel. It is found that the panel surface has a maximums temperature at the center and a minimums temperature along the border. It was prominent that the differing is about 10 °C in any case of the radiance at which the readings were possessed. This non-consistency in temperatures are close to theoretical results of temperature values are 83.23 °C at the center of the plane, and the response function is reduced gradually to 72.54 °C at the two sides of the plane.

Figures (3) and (4) dominate the isothermal contour of temperature distributions of (x-z), and (y-z) planes. These planes have represented the values of temperature distribution through the thickness of PV panel. It has been illustrated that x, and y axis representing the front of PV panel, and the end of z-axis is represented by the back cell in two planes. It has been indicated that the temperature variation between the front and back surface of the cell is 24.091 °C through the thickness of solar cell. This difference value is after the absorption of solar radiation under the value of power intensity is 945 W/m^2 at time 120 minutes. The response of temperature reduction is decreased gradually from 83.25 °C at the front to 59.203 °C at the rear surface of the cell panel.

Figure (5) represents the temporal distributions of temperature in top and back of PV panel. It has been observed that the two values of temperature are a function of time. It is indicated that the temperature raises with boosting time of exposing to solar radiation even the top or back temperature. Also, the difference between the two values is increased with increasing time. It has been seen a maximum difference value at a time of 120 minutes.

Figure (6) shows the spatial temperature distribution in penetration thickness of PV panel with time intervals of 30 minutes. It has been shown the temperature response of every interval time from the top to the back of panel through z-axis. It has been indicated the difference value increasing with increasing time. These results from figures 2 to 6 are confirmed with the theoretical results [3], and with experimental work [14].

Figures (7) and (8) explain the response premiums of Nusselt number and heat transfer coefficient at a transient state. It is establish that heat transfer coefficient excesses with increment time of PV cell is irradiated by solar radiation. The maximum value is 3.616 $W/m^2.K$ at time of 120 minutes. Similarly, in figure (8) the Nusselt number takes the same response with time. This is due to the Nusselt number is a function of heat transfer coefficient. These values are calculated under assumption conditions when sun radiation intensity is 945 W/m^2, no wind, and the ambient temperature is 25 °C at a period of times from 11 a.m. to 1 p.m.

Figure (9) displays the effect of rear surface temperature of PV panel on output performance of PV cell with different intervals time at average value 945 W/m^2 of solar irradiance intensity through a period of time of two hours from 11a.m to 1 p.m. on a day no wind effect. It is observed that the efficiency inversely proportional with values of rear surface temperature and time. The high value of efficiency is found by 16.5 % to 16% when the rear surface temperature is 27.97 °C to 35.13 °C and times 11:20 to 11:50 a.m. Then, the efficiency decreases when the rear surface temperature increases with time. Worst condition of efficiency was found by 14.2% when the rear surface temperature is 59.203 °C at time 1 p.m. This is due to the increasing of solar irradiation, and the electrical power decreases with increasing temperature. These results are agreed with results [4]. It will be recommended cooling the back surface of PV cell to excess its efficiency.

6. Validation of the Thermal Model

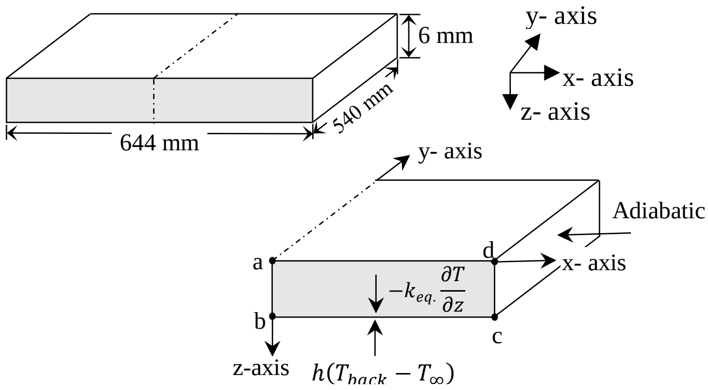
The schematic diagram of experimental rig for testing transient thermal model is illustrated in figure (10). It designed by the PV cell panel module type (FRS-50W) placed at 60° on horizontal surface. Temperature recorder device with thermocouple sensor type K was used to measure the back surface temperatures. An atmospheric condition such as wind speed is measured by hot wire anemometer model (YK-2005AH) at ambient temperature 25 °C. The solar intensity is measured by solar power meter device data logging model (TES-132), as shown in figure (11). These parameters were measured every ten minutes through periods of time from 11a.m to 1p.m on 8/3/2018 in Hillah city, Iraq.

7. Conclusions

- Newer transient thermal model has been investigated to expect the temperature distributions at various locations of PV panel domain. This model gives higher different value of temperature between the top and back surfaces, which were 24.091 °C, while the most authors predicted not more than 5 °C. This result gives more reliability for the simulation of the new model. This is due to the model predicted the actual value of radiation heat which was absorbed according to Eq. (3).

- It is found the operating temperature (back surface temperature) of PV cell increases with increasing the value of solar irradiation. Thus, the increasing in operating temperature causes decreasing in the efficiency of electrical power of PV cell.

- Parameters of free convection such as Nusselt number and coefficient of heat transfer are calculated at the back surface of cell. These parameters are indicated how much heat misfortunes through the rear surface of the PV cell. These are not enough for cooling and improving the performance of PV cell. Thus, it is recommended to use different methods of cooling. Phase change material (PCM) is the optima method to increase the rendition and efficiency of PV cell.



(b)

Fig. (1) Boundary conditions on PV solar cell

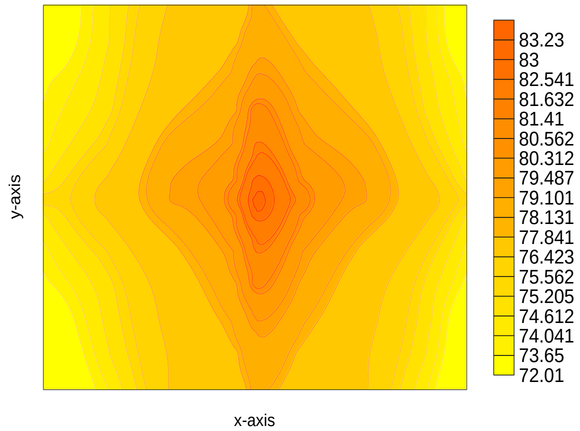


Fig. (2) Isothermal contour of the temperature distribution through top surface (x-y) plane of PV panel.

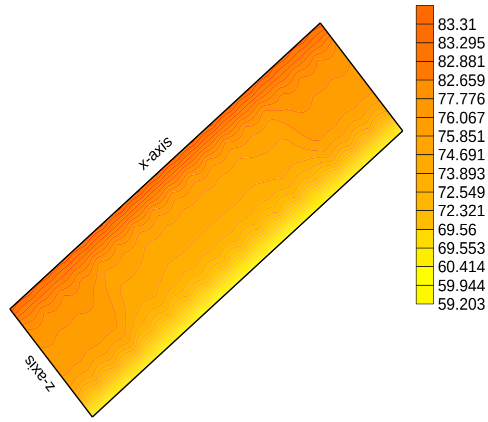


Fig. (3) Isothermal contour of the temperature distribution through front surface (x-z) plane of PV panel.

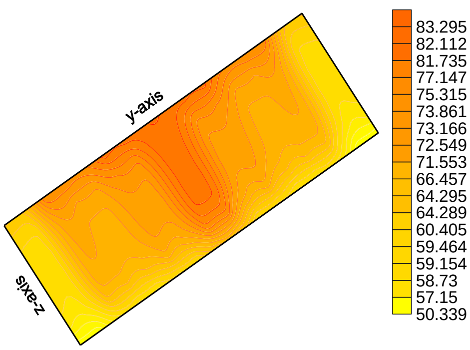


Fig. (4) Isothermal contour of the temperature distribution through side surface (y-z) plane of PV panel.

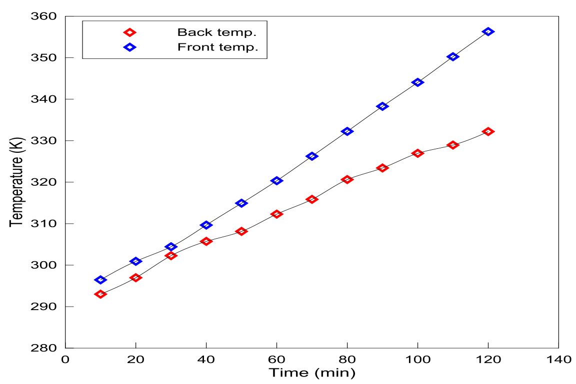


Fig. (5) Temporal distributions of temperature in front and back of PV panel.

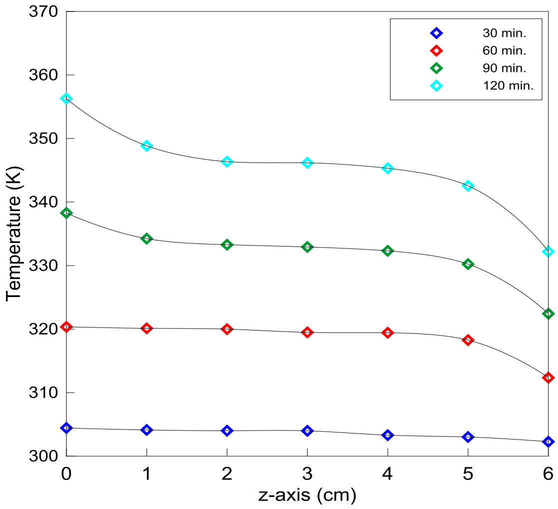


Fig. (6) Temperature distribution through z-axis of PV panel at different intervals time.

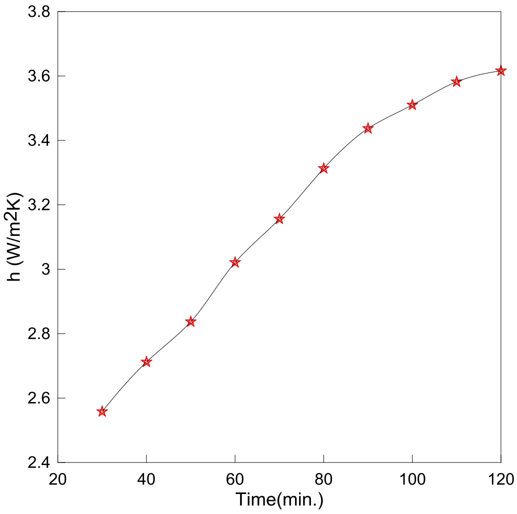


Fig. (7) Heat transfer coefficient of PV panel with time.

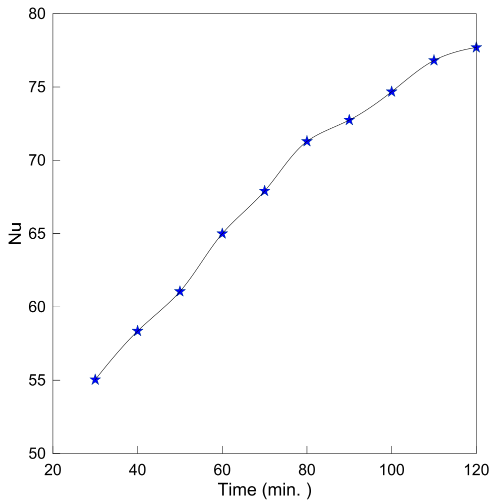


Fig. (8) Nusselt No. of PV cell with time.

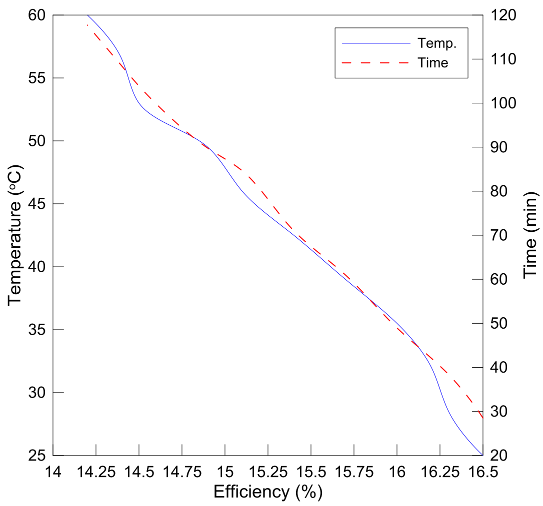
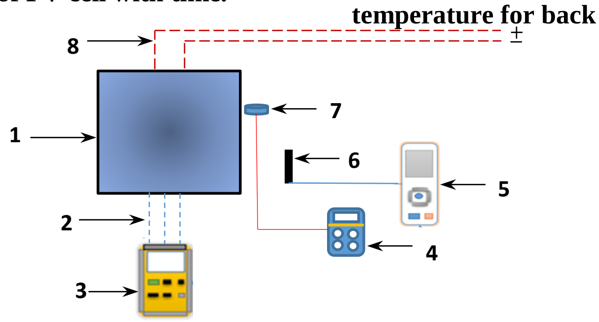


Fig. (9) Efficiency with time and temperature for back surface of PV panel.



1	PV Panel	5	Hotwire anemometer
2	Thermocouple wire	6	Wind speed sensor
3	Temperature recorder	7	The Lens of the power meter
4	Solar power meter	8	Electrical wire

Fig. (10) Schematic diagram of the experimental rig.

(a) (b) (c) (d)

Fig. 11. Photograph of (a) PV panel, (b) data logging solar power meter, (c) hot wire anemometer, (d) temperature recorder device.

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أنموذج رياضي لدراسة توزيع درجات الحرارة داخل الخلية الكهروضوئية (الفوتوفولتائية)

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الخلاصة

تم تطوير انموذج رياضي لمحاكاة درجة الحرارة المكانية والزمانية داخل لوح الخلية الكهروضوئية ، وذلك بالحل العددي لمعادلة الحرارة غير المستقرة وبثلاثة أبعاد ، باسخدام طريقة الفروقات المحددة لتقليل الاخطاء الناتجة من الحل. يتضمن هذا النموذج تاثير المواد المكونة للوح الكهروضوئي من خلال خواصها البصرية والحرارية عند تعرضها المباشرإلى ضوء الشمس . الفرق في درجة حرارة عبر السطح العلوي والخلفي للوح الخلية الضوئية كان 24.091 درجة مئوية. تتناسب كفاءة الخلايا الشمسية الكهروضوئية عكسيًا مع درجة حرارة التشغيل في السطح الخلفي للوحة الكهروضوئية. .تعتمد درجة حرارة التشغيل على الظروف المتغيرة للغلاف الجوي ، وتأثيرات سلوك مواد الألواح وهيكل التركيب. تم تحديد معامل فقدان حراري للحمل الحر على السطح الخلفي للوحة الكهروضوئية. يشير هذا التحليل إلى تأثير معامل فقدان الحرارة بالحمل الحرعلى درجة حرارة التشغيل للوحة الكهروضوئية وكفاءتها.

الكلمات الدالة: الخلية الفوتوفولتائية، موديل حراري، شدة الاشعاع الشمسي، التوزيع الحراري.