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(Review Article)

Modeling and analysis of thermal photovoltaic energy generator using COMSOL multiphysics

Manish Kumar Sharma *, Ashish Kumar Jain and Sandeep Gupta

Department of Electrical and Electronics Engineering, Dr. K.N. Modi University, Newai, Rajasthan, India.

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Abstract

Because of to their versatile energy choice alternatives, immovable elements, and opportunity for effective energy generation, thermophotovoltaic techniques have a vast range of achievable applications. For illustration, these devices could help us to offer convenient energy. Nevertheless, first enhance the performance of thermo-photovoltaic cell unit devices along with decrease system costs and system temperatures. To achieve such objectives, we use simulation to evaluate and improve their thermo-photovoltaic cell unit models.

This research regarded as the different alternatives of enhancing system operation via successful deal with the operating circumstances. It examined solutions of the system formation for much better system performance and energy output and at bare minimum quantity working expenses. The number of mirrors and photovoltaic devices for employ in the construction had been set at eight as traditional for the procedure. A novel energy technique was constructed and was used to reproduce the energy effectiveness of the thermal photo voltaic modules. The boundaries situations utilized for the materials involved were defined and the appropriate physics utilized in the analysis of various operating circumstances that affected the system effectiveness.

It is possible to reduce the costs of PV systems by using small area PV cells, which require some special mirrors to focus radiation onto photocells. Based on COMSOL Multiphysics (version 5.5) as a commercial FEM package, this paper develops a basic thermo-photovoltaic cell unit model. A variety of options examined for optimizing the operation of the system by controlling operating conditions effectively. For a two-dimensional system, it was demonstrated the correct physics to apply when studying various operating conditions which affected system performance.

Keywords: COMSOL Multiphysics; Finite Element Method; Photovoltaic Cell; TPV

1. Introduction

A photovoltaic (PV) system converts solar energy directly into electricity. An alternative method is to concentrate high-temperature heat onto a PV module for electricity generation, such as through the use of devices. It is not the photovoltaic module itself that receives the solar radiation from photovoltaic but rather the concentrators that do so. It is called concentrators or solar collectors, and these devices receive the sun's radiation in the form of heat, which is transferred to the thermos-photovoltaic cells through mirrors or lenses. Thermal considerations are being taken into account when assessing the potential of thermal photovoltaics.

An electrical power generator is connected to a heat engine (usually a steam turbine) which converts the light to high-temperature heat [1]. Figure 1 shows that solar energy is collected and converted into high-temperature heat in the first stage, then the heat energy is converted to electricity in the second. As opposed to photovoltaic plants, which produce

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* Corresponding author: Manish Kumar Sharma

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electrical power by solar radiation on a photo-voltaic component, photovoltaic plants use concentrators that transform the radiation immediately into electrical power. A solid-state inverter converts the direct current of the PV cells to alternating current.

A photovoltaic system requires one or more types of optics: a parabolic dish, a parabolic trough collector, a power tower, and a compact linear Fresnel reflector i.e. CLFR [2]. Thermo-photovoltaic systems are most commonly used in California, where they have been operational for over 20 years [2].

Additionally, a few concentrated technology options have been constructed in recent years, however they seem to be just as promising. On a large scale, CLFRs could be much cheaper to construct [3,4]. As a source of renewable energy that produces no greenhouse gas emissions, concentrated solar power is an appropriate technology to reduce climate change; it produces electricity and does not emit greenhouse gasses. Due to its thermal storage capability and firm electric capacities, CSP plants are flexible and enhance energy security. So far, a total of 2304 megawatts (MW) of CSP have been installed throughout the world [4], with Spain and the United States leading the way [2]. Morocco and South Africa are also building solar plants, and Algeria, Australia, Egypt, and Morocco offer smaller solar fields that are regularly integrated into larger fossil fuel plants. CSP is still only being considered by a small number of countries worldwide [4].

Steam turbines, in contrast to PV technologies, generate all the necessary supplementary services and dispatchable power, such as ramping supplies, control and spinning reserves [4]. Additionally, energy can be located in these plants for potential transformation to electricity. CSP plants can continue to generate electricity without having disruption even when clouds prevent the sun, after sundown, or in the earlier morning when electrical power demand increases, whenever they are put together with thermal storage space capacity of a number of hours of full-capacity systems [4,13].

A considerable amount of heat can be produced from them for industrial processes, and they also possess the potential for co-generation of heat, cooling, and power, and desalination of water [4]. To optimize Thermo-Photovoltaic Cell Unit system operation, this study models, simulates, and analyses the system. As part of this process, a two-dimensional distribution of temperatures in the Thermo-Photovoltaic Cell Unit panel is determined in order to interpret the results and apply them in a similar work environment. To increase efficiency, it is important to maximize radiation heat. There are several reasons why PV efficiency is low, including a lack of conversion of light to electricity and increased temperatures in the PV cells. Using high-efficiency PV cells is a cost-effective way of reducing the effect of these two factors [5,6]. Researchers and engineers are now experimenting with smaller-area solar panels and focusing the radiation on them using mirrors to reduce costs. These cells, however, can only be exposed to a certain amount of radiation in a safe manner: too much radiation intensity will cause the cells to overheat and burn. To maximize system performance and power output, the system geometry and operating conditions need to be optimized. In designing and developing the thermo-photovoltaic cell unit system, modeling and simulation were used. These equations and others were solved using COMSOL Multiphysics' tool flow.

Based on the developed model, a number of studies were conducted to evaluate the module's electrical and thermal performance. A powerful integrated desktop environment was provided by COMSOL's basic modelling workflow which provided access to all functionality and an overview of the model at a glance. Multiphysics models, which facilitate the solution of coupled physics phenomena, were developed based on the conventional model for the type modelled. In addition, it supports advanced material properties and has built-in physics interfaces. A two-dimensional model was built, which integrated physical quantities such as substance attributes, and equations underpinning the design. Solid and fluid domains, boundaries, edges, and points were instantly influenced by the factors, expressions, or numbers regardless of the computational mesh. In order to design high-performance cells, two-dimensional and three-dimensional simulations are necessary since they enable correct interpretation of two-dimensional and three-dimensional finite element analyses of semiconductor devices with compound and silicon components and provide reliable results [7]. When solar cells have conventional geometry but are highly concentrated, one-dimensional simulations are often not sufficient.

2. Energy analysis of a thermal photovoltaic system

Temperature and efficiency of the cells examine the working conditions of the thermo-photovoltaic cell unit system. Most thermo-photovoltaic cell unit devices have an efficiency between 1 and 20% [8]. PV performance is inversely associated to working heat range due to the radiation losses not transformed into electric power. The thermo-photovoltaic cell unit is also unable to maximize radiation heat transfer because heat transfer via conduction within the system also increases cell temperature. Temperature increases in the cells should be minimized to the greatest extent possible. A complex determination of temperature is required due to the characteristics of illumination and the technology underlying the cell construction. In order to determine the temperature of a cell using the concentration factor, [1] derived equations based on their experimental findings. According to Equation 1, cell temperature is expressed [14].

$$T_c = T_o + \frac{V_{oc}(T_{c,}C) - V_{oc}(T_{c,}C_o)}{\beta(C)} \text{ ....(1)}$$

Empirical data were obtained about the variables examined in Equation 1 from [9].

Thermophotovoltaic Cell temperature, which represents the unknown, was found to be a significant factor in determining open circuit voltage. A graphical relationship was found to solve this problem by Cotal et al [8] and Renno et al [1], which determined that Vo is only dependent on the concentration factor. In Equation 2, Vo is expressed as follows:

$$V_{oc}(C) = 2.5847 + 0.085283.\ln(C) \text{ .... (2)}$$

A voltage thermal coefficient is also calculated by Equation 3 according to Steiner et al. (2011), based on C.

$$(C) = -0.006424 + 0.00036233\ .\ ln\ (C) \text{ .... (3)}$$

Equation 4 gives the temperature of the cell based on these assumptions.

$$T_c = T_o + \frac{V_{oc}(T_{c,}C) - V_{oc}(T_{c,}C_o)}{|\beta(C)|} \text{ .... (4)}$$

In order to figure out the performance of the cell, one need to know the cell temperature first. Likewise, Steiner et al. [9] Utilized some experimental layouts to figure out the theoretical equation between the amounts examined. At the similar cell temperature, the performance minimizes as the concentration factor improves.

Using Equation 5, we can calculate the efficiency of the cell.

$$\eta_c - \eta_r = \frac{d\eta}{dT}.(T_C - T_r) \text{ .... (5)}$$

$$\frac{d\eta}{dT} = -0.09167 + 0.005757.\ln(C) \text{ .... (6)}$$

where
Tr = 25 °C
ηr = efficiency at reference temperature and

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3. Methodology

The Thermo-photovoltaic cell unit system generates electricity through radiation and combustion of fuel. In Figure 1, a thermo-photovoltaic cell unit system with heat transferred through a medium converts heat to electricity [10], whereas in Figure 2, we see a mathematical model for the thermo-photovoltaic cell unit system in Figure 1. thermo-photovoltaic cell unit produce electricity by burning fuel and radiating heat (flame) at the center of concentrators through the heat they generate. This is shown by the chart that illustrates the geometry of the cells and how they work. The operation and temperature distribution effects of similar thermo-photovoltaic cell unit systems were analyzed using 2D models, as shown in Figures 3.

PV cells grabbed the rays and transformed it into electrical power by using fuel inside an emitting device that radiates intensive heat. As heat distributions rely on materials in common, the material attributes needed to be described (Yahyavi, et al., 2010). For this product, the subsequent components were included: heater, cell type, and mirrors, attached to the PV cells, and environment circumstances. PV cells have a restricted operating heat simply because of the type of materials used. Using the heat exchange application to make use of surface-to-surface rays interface, Peter et al. (2015) researched the effect of operating circumstances (flame temperature) on thermo-photovoltaic cell unit technique performance and component heat [11].

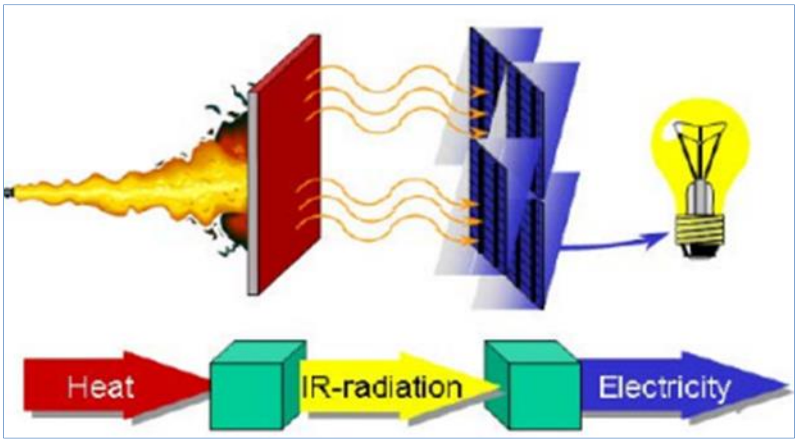


Figure 1 Operating principle a thermal photovoltaic system

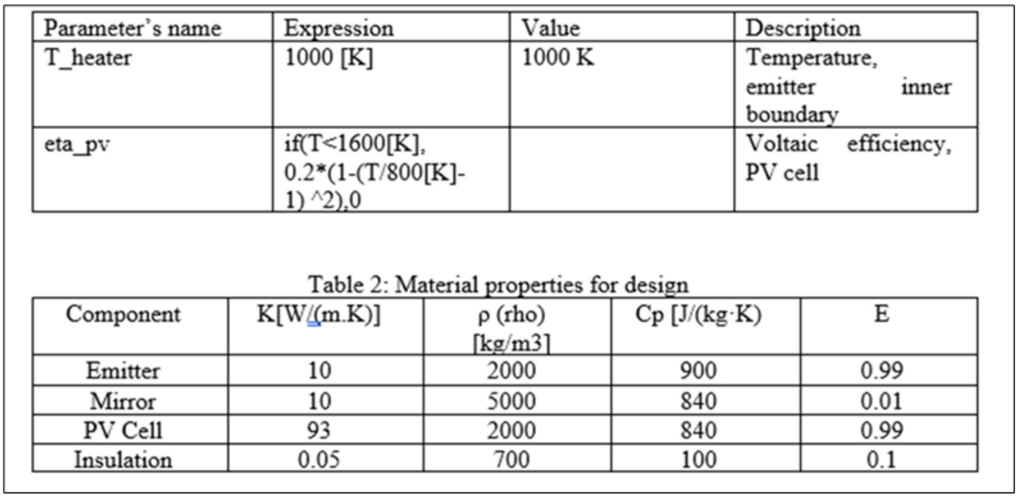
To reduce the temperature of the PV cells, their back-sides (interfaces with the insulation) were assumed to be water-cooled. Because heat flowed across the different boundaries, conduction must have taken place . Using a specific temperature for the emitter. In Table 1, the model indicates the theater on the inner boundary. As a boundary condition for the outer emitter, surface-to-surface radiation was taken into account. In Table 2, the low emissivity applied to the mirrors was simulated by considering radiation at all boundaries. In addition to the PV cell inner boundary conditions, the insulation internal boundary conditions were also applied. There is, however, a greater emissivity in PV cells than in insulation. A fraction of the irradiation is converted into electricity instead of heat by the PV cells. Equation 6 defines a boundary heat source q as a source of heat on the inner boundaries of the heat sinks.

$$q = -G\eta_{pv}$$ ……………(6)

where G = irradiation flux (W/m^2)

ηp = voltaic efficiency of the PV cell.

Table 1 Global parameters



Parameter's name	Expression	Value	Description
T_heater	1000 [K]	1000 K	Temperature, emitter inner boundary
eta_pv	if(T<1600[K], 0.2*(1-(T/800[K]-1) ^2),0		Voltaic efficiency, PV cell

Table 2: Material properties for design

Component	K[W/(m.K)]	ρ (rho) [kg/m3]	Cp [J/(kg·K)	E
Emitter	10	2000	900	0.99
Mirror	10	5000	840	0.01
PV Cell	93	2000	840	0.99
Insulation	0.05	700	100	0.1

4. Methodology Modelling and simulation of thermo-photovoltaic cell unit system

In COMSOL Multiphysics version 5.1, the geometrical, definition, dimension, and meshing parameters were defined. Thermo-photovoltaic cell unit was first modeled as a round and the other resources were also modeled as outlines, as revealed in Figure 2. thermo-photovoltaic cell unit system model parameters are shown in Figure 2. Thermal reduction was achieved by water-cooling the PV cells on their flipside (the line with the insulation). Since different boundaries were in contact with each other, conduction was always present. Table 1 indicates how the typical model simulated the emitter with a temperature, Theater, on the innermost edge. At the exterior emitter edge, radiation (surface-to-surface) was measured. In Table 1, the heater's global definition is given, while the PV cell's global definition is given in Table 1. Mirrors, PV cells, insulation, and emitters have been modeled as labelled in Table 2 with radiation occupied into interpretation at all limitations.

4.1. Outer Model Evaluation

The measurements model was tested at a significance level of 5% with several invalid and unreliable aspects as shown in Figure 1, with the results of the outer model.

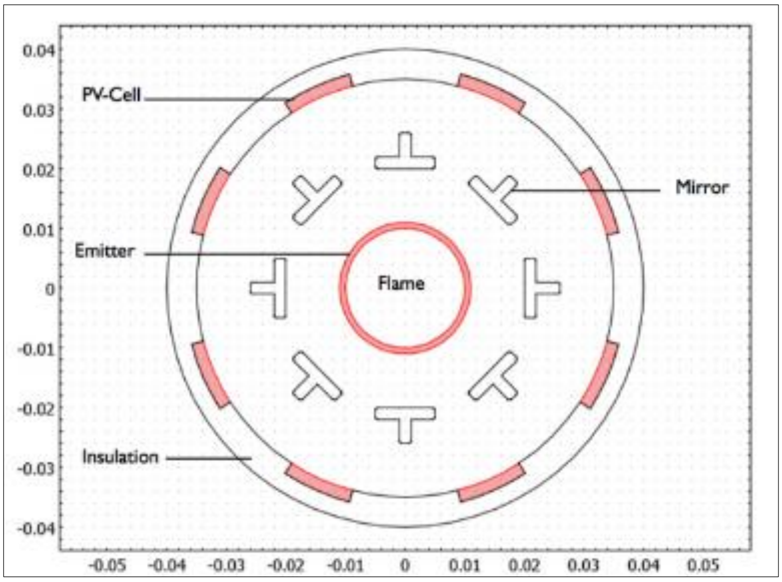


Figure 2 System model geometry

In command to model and simulate the materials, we used the specifications and materials described in Table 2.

This includes the emitter on the inner boundary with a specific temperature and the mirrors on all boundaries with low emissivity assumed. In addition, the primary unit and insulation were assigned high and low emissivity values, respectively. The relevant material properties are listed in Table 2.

Siddiqui et al. (2012) define Equations 7 and 8 as equations describing heat transfer in solids and fluids (Siddiqui et al., 2012).

$$q = -k\nabla T \qquad \ldots\ldots\ldots\ldots\ldots\ (7)$$

$$\rho C_p u . \nabla T + \nabla . q = Q + Q_{ted} \qquad \ldots\ldots\ldots\ldots\ldots\ (8)$$

In Equation 9, the solar cells' efficiency is defined as a role of the ambient temperature T.

$$\eta_{pv} = \left\{\begin{array}{c} 0.2\left[1-\left(\frac{T}{800\,K}-1\right)^{2}\right] T \le 1600\,K \\ 0\,T \; > 1600\,K \end{array}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ (9)$$

where ρ = the density
Cp = Heat capacity
T = temperature,
k = thermal conductivity
q = heat transferred by conduction
Q = internal heat generation
u = fluid velocity

An investigation has been conducted to study the impact of effective environments (flame temperature) on the productivity of a representative thermo-photovoltaic cell unit and its electric output power. In addition, geometry changes, such as material usage and specification, were considered when wily the structure. In addition to examining the effects of temperature distribution, efficiency, and power output of thermo-photovoltaic cell unit, we investigated the influence of mirror number on mirror number on the temperature distribution, efficiency, and control productivity of thermo-photovoltaic cell unit. Simulating the emitter with a specific temperature on its innermost edge, T_{heater}, was included in the model. Boundary conditions included surface-to-surface fallout at the outer emitter boundary.

Simulations were conducted using low emissivity and radiation taking into account all boundaries. All boundaries are subject to conduction. Fallout edge environments were also used at the inside limits of PV cells and insulation. According to Table 2, emissivity values assigned to thermos photovoltaic unit with high emissivity were used in order to convert a segment of sun irradiation into energy as an alternative of heat. By simulating water cooling in the thermos photovoltaic cells, a portion of the irradiation is converted to energy as a substitute of heat.

Based on Equation 7, a boundary heat source q was accounted for in the interior the ambient temperature. According to Equation 9, the cell efficiency, depends on the local temperature. 800 K was applied as the local temperature. Using its generalized equation, this temperature is the best temperature for PV cells to have a voltaic efficiency of 0.2. By setting parameters as in Equations 11 and 12, the model applied convective water-cooling to the outer edge of the PV cells to prevent overheating.

$$Q = \frac{(1-\eta_{pv}).S.A_{Panel}}{V_{Pc.cell}} \quad \ldots\ldots\ldots\ldots\ldots\ (10)$$

where η_p = PV panel efficiency
A_{panel} = PV panel front area
$Vpc.cell$ = the PV cell volume

$$h = 50W/(m^2\,.K) \quad \ldots\ldots\ldots\ldots\ldots\ (11)$$

$$T_{amb} = 273\,K \quad \ldots\ldots\ldots\ldots\ldots\ (12)$$

The parameters for convective cooling applied at the insulation's outer boundary were given in Equations 13 and 14.

$$h = 5W/(m^2\,.K) \quad \ldots\ldots\ldots\ldots\ldots\ (13)$$

$$T_{amb} = 293\,K \quad \ldots\ldots\ldots\ldots\ldots\ (14)$$

Modeling work involving this type of physics and equations that govern the application of the physics to various selections including edges, boundaries, and points.

5. Results and Discussion

The outcomes in Figures 3 indicate the visual heat distribution for the thermo-photovoltaic cell unit devices at eight mirror configurations, that had been subjected to working emitter temperature circumstances of 2000 K.

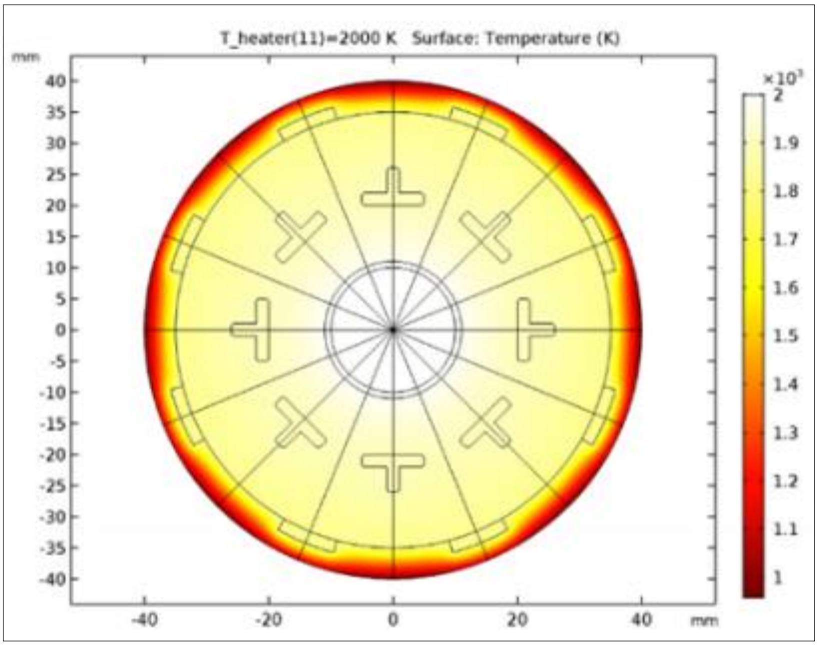


Figure 3 The Heat Distribution at 2000 °C

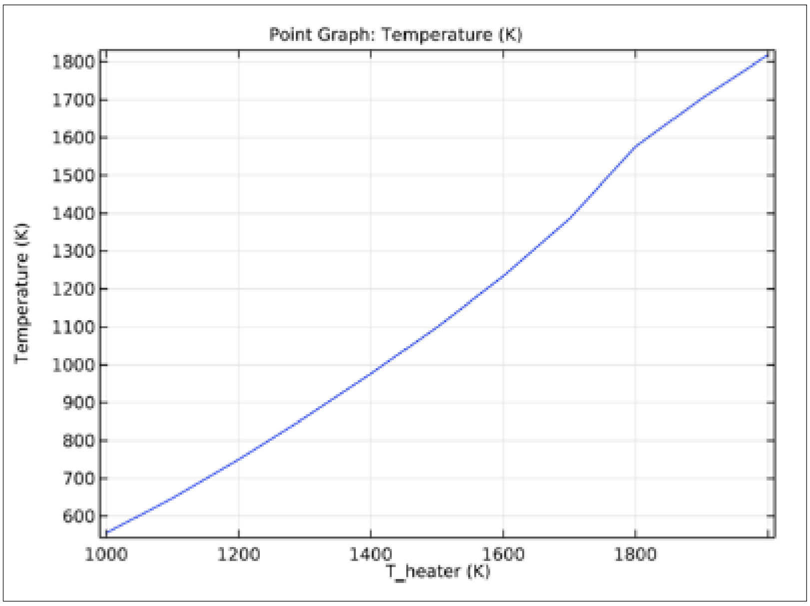


Figure 4 Thermo-photovoltaic cell unit system temperature *V/s heater temperature (K)*

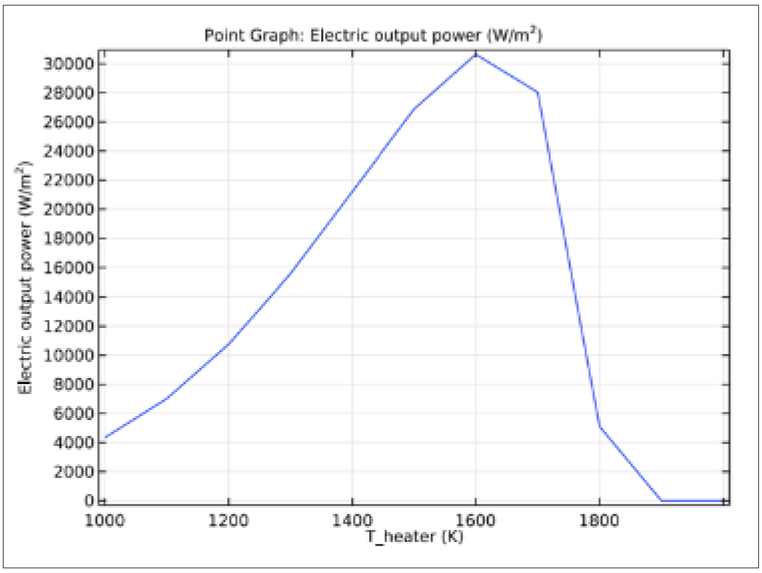


Figure 5 Thermo-photovoltaic cell unit system Electric power output (W/m^2*) V/s heater temperature (K)*

The construction with eight mirrors was established as the consistent and the geometry was developed as outline in figure 2. The outcomes demonstrated that the thermo-photovoltaic cell unit structure encountered an outstanding heat circulation that diverse practically linearly along with the working circumstances.

The fixed temperature circulations are clearly symbolized in Figures 4, wherever the PV units attained various temperature values for the devices. While the cell's heat is higher than 1600 K, the performance is 0. Therefore, the optimum functional temperature for the PV cell structure is 1600 K. The calculation is designed to figure out exactly how the emitter's heat impacts the temperature of the Thermo-photovoltaic cell unit structure and the electric output energy. The unit temperature plot implies that the emitter temperature range must be within ~1800 K to retain the Thermos-photovoltaic cell under its highest functioning temperature of 1600 K. The electric energy output demonstrated figure 5. it demonstrates that the highest electric power is attained when the emitter heat is ~1600 K.

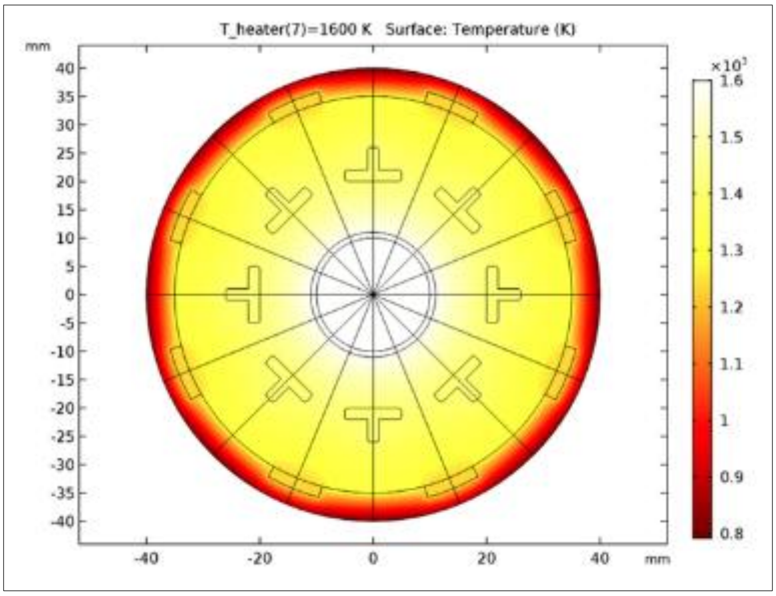


Figure 6 Heat circulation in thermophotovoltaic cell unit at Temperature 1600K

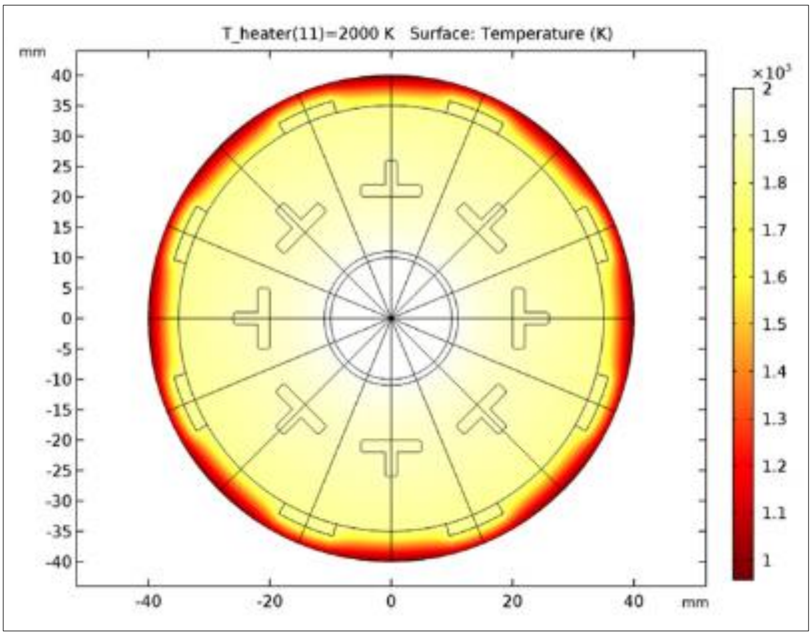


Figure 7 Heat circulation in thermophotovoltaic cell unit at Temperature 2000K

The heat circulation in the thermo-photovoltaic cell unit for the remarkable working condition is demonstrated in the figure 6 and in comparison, to a heat that surpasses this working temperature displayed in the figure 7. The two figures emphasize how the device's heat circulation varies due to functioning conditions and identified the remarkable emitter heat of 1600 K, the thermo-photovoltaic cell unit are heated up to a supportable temperature of marginally above 1200 K. but the exterior part of the heat retaining material extends to a heat of 800 K, revealing that a significant quantity of heat is shifted to the bordering air. The irradiative flux substantially differs close to the thermo-photovoltaic cell unit area as well as insulation material. The graph reveals that the deviation is induced by shadowing and is associated to the mirror placement situations. Utilizing this plot, might improve the cell dimensions and location of the mirrors for a thermo-photovoltaic cell unit design. The final results in Figures 3 to 7 revealed that, the thermo-photovoltaic cell unit system achieved the efficiency of 19.8%. The designs use the described modelling guidelines, The power developed in the eight mirrors was 31800 W/m^2.

6. Conclusion

Finally, thermophotovoltaic (TPV) cells are auxiliary energy transfer devices that capture or dissipate heat lost in other individual power generation systems (or power plants), for example solar cells. Not only that, but thermophotovoltaics (TPV) for solar photovoltaics (or in addition) are commendable but the difference is that TPV operates at night and in cold weather (low temperatures). Also, TPV is very suitable for small- and large-scale combined energy and heat and uses natural gases in its manufacture. Later, the TPV is not heavy and the battery can be reused or reused in the UAV. Last but not least, thermophotovoltaics are used in steel mills to convert electricity 24 hours a day for a week and therefore, there is a huge market JAX crystal IR volume and a large number of new applications. Important for The significant disadvantage of TPV is that it is very expensive to implement and as a result, not everyone can benefit from it. For Future work, to improve efficiency, we can influence filters or selective emissions to create emissions in the optimized wavelength range for a specific photovoltaic (PV) converter. Therefore, in this way thermophotovoltaics can overcome the traditional challenge of conventional PV, which leads to efficient utilization of the entire solar spectrum.

Compliance with ethical standards

Acknowledgments

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