Optimizing TPV System for Maximize Surface to Surface Radiation and Minimize Cells Temperature

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Abstract

A thermo photo voltaic (TPV) cell generates electricity from the combustion of fuel and through radiation. The fuel burns inside an emitting device that radiates intensely. TPV cells capture the radiation and convert it to electricity. TPV systems, unlike typical electronic systems, must maximize radiation heat transfer to improve efficiency. To improve system efficiency and reduce system costs, engineers should work with smaller area TPV cells and then use mirrors to focus the radiation on them. However, there is a limit about the amount of beams that can be focused on TPV cells. If radiation intensity becomes too high, the cells can overheat. Thus, there is a need to optimize system geometry and operating conditions to achieve maximum performance at minimum material costs. The present article investigates the influence of operating conditions on the system efficiency and the temperature of components in a typical TPV system. The results show that the device experiences a significant temperature distribution. It also, shows that the optimal operating temperature is between 1700 K and 1900 K, where the electric output power is maximized.

Keywords: Thermophotovoltaic; Photovoltaic modeling; Radiation modeling

1. Introduction

Interests in thermophotovoltaics systems, devices capable of converting heat directly into electric power, started in early 1960s [1, 2] as a result of the fundamental limitation of the conversion efficiency of broadband radiation into electricity by means of photovoltaic cells [3]. It has only been in the last decade that thermophotovoltaic (TPV) systems were built due to the breakthrough in photo cells such as GaSb and InGaAs, which efficiently convert low-bandgap (<0.7 eV) thermal energy into electricity. Indeed, Incident and output power densities are much larger than flat-plate PV modules because of geometric considerations. The output power densities may eventually be as large as 5 W/cm^{-2}. i.e. 50 times that of a flat-plate PV system, assuming that the semiconductor converters work as efficiently as solar cells [3]. However, so far applications of TPV system have been limited to large (>10 kW) to medium (>100 W) size generators with an overall efficiency of about 10%. The TPV system promises to be a very clean and quiet source of electrical power with no moving parts and high power density, using a wide variety of energy sources. An important advantage is that the electric power generated by these systems is produced every time the user needs it and is independent of sunlight availability. Thanks to this characteristic, these systems are not limited to being used in the day or linked to a battery pack or an energy buffer, like the traditional no grid connected photovoltaic systems. The other possible advantages of this kind of generator are: low noise generated; possibility to be used in cogeneration energy systems of heat and electricity [4]; low pollution; and versatile fuel usage [3].Potential attractions of TPV include high-power density, including fuel versatility, portability, silent operation, operation that is independent of the sun, and low maintenance costs. Possible applications include stand-alone domestic gas furnaces, power systems for navigation of sailing boats, silent power supplies on recreational vehicles, co-generation of electricity and heat and many others. The heat recovery system is one of the critical components in TPV generators based on liquid or gaseous fuels. Heat recovery from the exhausts at very high temperature allows pre-heating the combustion air and, consequently, increasing the global efficiency of the system. Military organizations have also taken a keen interest in TPV conversion because of possible strategic advantages that may be realized [5]. A TPV generator consists of a heat source (i.e. nuclear fuel, hydrocarbons, waste heat etc. [6,7]), a selective emitter/filter system and photovoltaic cells. Fig. 1 depicts the general operating principle. TPV cells have a limited operating temperature range that depends on the type of material used. Solar cells are limited to temperatures below 80 °C, whereas high efficiency semiconductor materials can withstand as much as 1000 °C.

To improve system efficiency, engineers prefer to use high efficiency PV cells, which however can be quite expensive. To reduce system costs, engineers work with smaller area PV cells and then use mirrors to focus the radiation on them. Thus, engineers must optimize system geometry and operating conditions to achieve maximum performance at minimum material costs. The present article investigates the influence of operating conditions on the system efficiency and the temperature of components in a typical TPV system.

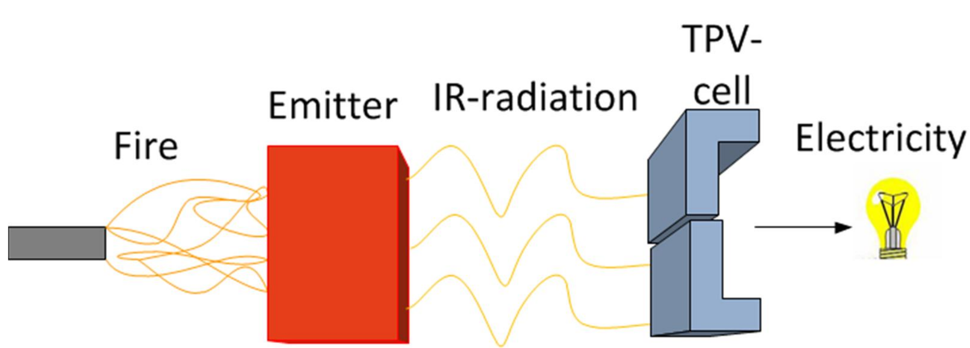

Fig. 1 Operating principle of a TPV device

2. Modelling

The geometry and dimensions of the system under study is shown in Fig. 2. This system consists of 4 mirrors for focusing beam radiation on 4 TPV cells. The fuel burns inside an emitting device that radiates intensely. To reduce the temperature of cells, the TPV cells are water cooled between their back side and the insulation surface. The governing equation for two dimensional and unsteady energy conservation, which describes heat fluxes, radiative flux and conductive flux, is as follows:

$$\rho C_p \frac{\partial T}{\partial t} + \nabla(-K\nabla T) = Q \qquad (1)$$

where ρ is the density, k denotes the thermal conductivity, Q represents the volume heat source and C_p is the specific heat at constant pressure. For boundary conditions, conduction is always assumed in this boundary condition equation:

$$n.(-K\nabla T) = h(T_{inf} - T) + \left(\frac{\epsilon}{1-\varepsilon}\right)(J_0 - \sigma T^4) + q \qquad (2)$$

Where *n* is the surface normal vector, *h* is the convective heat transfer film coefficient, T_{inf} equals the temperature of the convection coolant, ε equals the surface emissivity, J_0 is the surface radiosity expression, and σ equals the Stefan-Boltzmann constant.

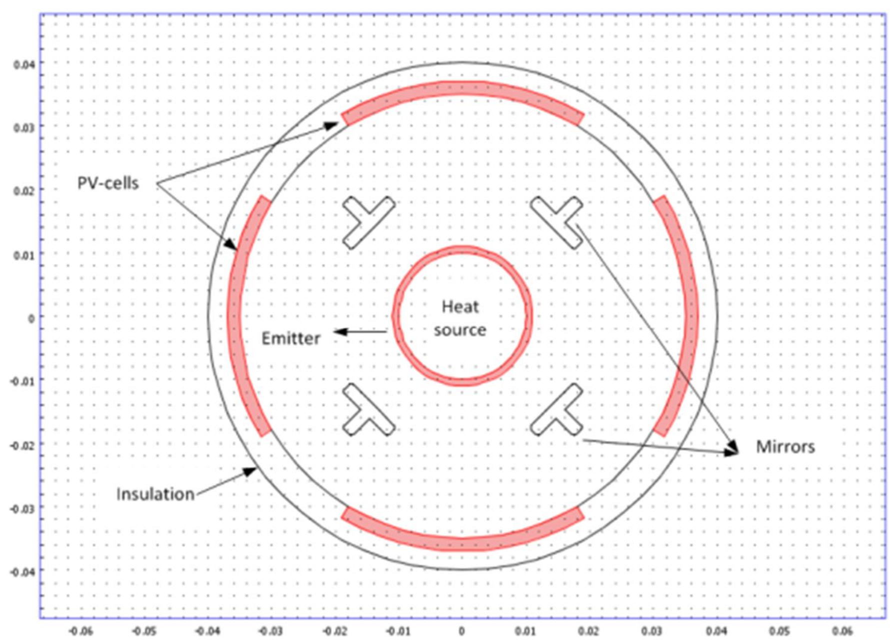

Fig. 2 Geometry and dimensions of the modeled TPV system

On the inner boundary the emitter is modeled with a specific temperature, T_{flame}. At the outer boundary, radiation on surface is considered. The mirrors are simulated by considering radiation on all boundaries and applying a low emissivity. Further, the PV cells convert a fraction of the irradiation to electricity instead of heat. Heat sinks on their inner boundaries simulate this effect according to:

$$q = G\eta_{TPV} \qquad (3)$$

where G is the irradiation flux and η_{TPV} is the TPV cell's voltaic efficiency. The latter depends on the local temperature, with a maximum of 0.2 at 800 K [8]:

$$\eta_{TPV} = \begin{cases} 0.2\left(1 - \left(\frac{T}{800} - 1\right)^2\right) & T \leq 1600K \\ 0 & T > 1600K \end{cases} \quad (4)$$

Convective water cooling at the outer boundary of the TPV cells is applied by setting h to 50 W/(m^2·K), and T_{inf} to 273 K. Finally, at the outer boundary of the insulation, convective cooling with 5 W/(m^2·K) for *h* and 293 K for T_{inf} is applied.

3. Results and Discussion

The stationary solution for a range of emitter temperatures from 1000 K to 4000 K is calculated using a commercial finite element code. Fig.3 depicts the stationary distribution at operating conditions with an emitter temperature of 4000 °K. It can be seen that the device experiences a significant temperature distribution that varies with operating conditions.

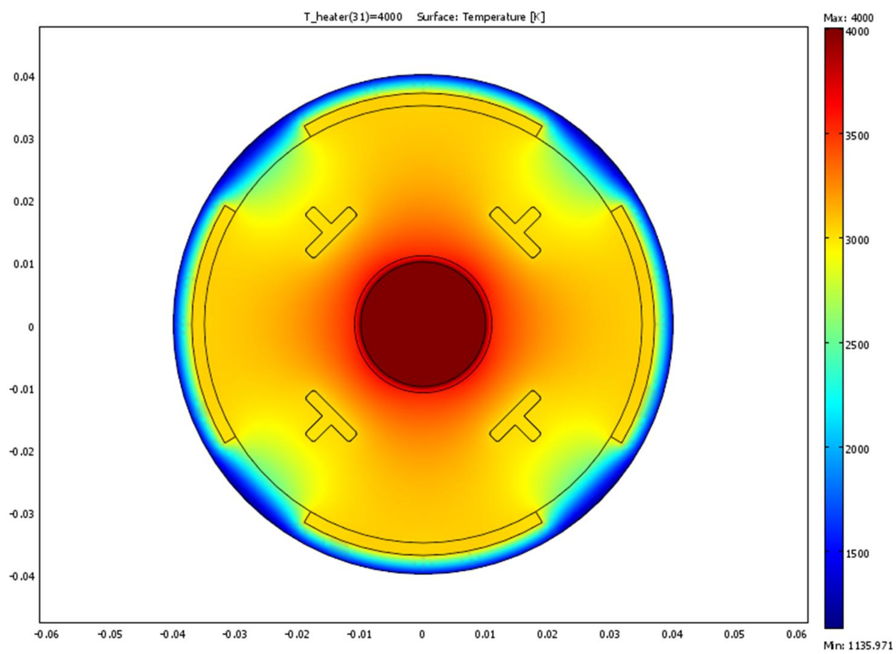

Fig. 3 Temperature distribution in the TPV system for 4000 °k as the emitter temperature.

Temperature of the TPV cells is illustrated in Fig. 4 for different emitter temperature. As it is clear, the TPV cells reach a temperature of approximately 3000 °k. This is extremely higher than their maximum operating temperature of 1600 °k, which in higher temperature the efficiency is zero.

The output electric power is shown in Fig. 5 for different emitter temperature. The optimal emitter temperature for this system is 1700 k and 1900 k, where the electric power has its maximum values, as seen from Fig. 5.

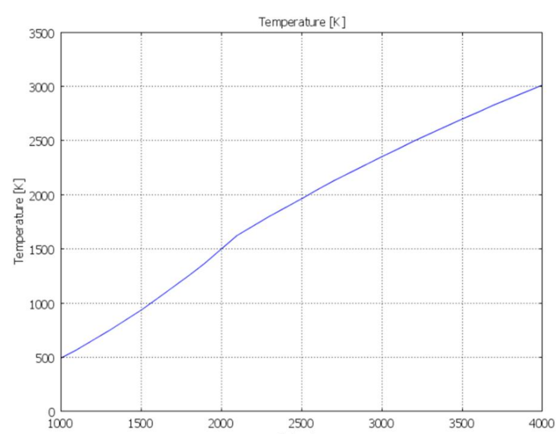

Fig. 4 TPV cell temperature versus emitter temperature.

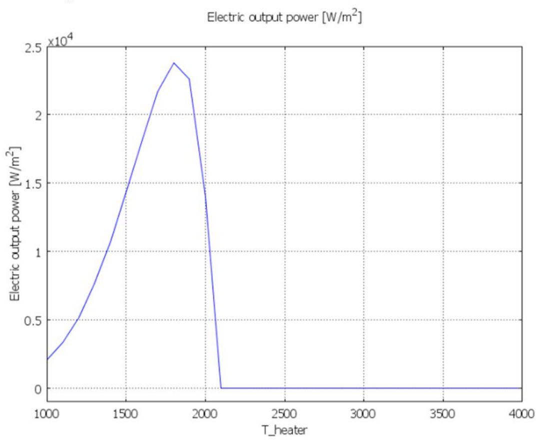

Fig. 5 TPV output electric power versus emitter temperature.

The irradiative flux along with a quarter of the circumference separately at 2000 °k as emitter temperature is depicts in Fig. 6. The irradiative flux varies significantly along the surface of the insulation jacket and TPV cell. This pattern is due to the position of the mirrors and is an effect of shadowing.

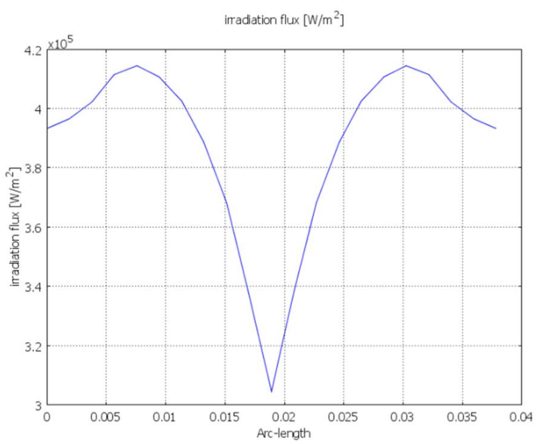

Fig. 5 Irradiation flux along the insulation and TPV cell surface for one quarter of the system.

4. Conclusion

A numerical analysis on a typical TPV system has been performed. The influence of operating conditions on the system efficiency and the temperature of components has been investigated. The results were presented for different emitter temperature. The major observations from the present study can be summed up as follows:

- The optimal operating temperature for having maximum efficiency is between 1700 and 1900 °k.
- The irradiative flux varies significantly along the surface of the insulation jacket and TPV cell due to the position of the mirrors.
- The TPV cells reach a temperature of approximately 3000 °k when the emitter temperature is 4000 °k, which is extremely higher than their maximum operating temperature of 1600 °k.

7. References

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