Performance evaluation of thermophotovoltaic GaSb cell technology in high temperature waste heat

Z Utlu[1] and B S Önal[2]

[1] İstanbul Gedik University, Engineering Faculty,
    Department of Mechanical Engineering, 34876, Kartal, İstanbul,Turkey
[2]İstanbul Aydin University, Institute of Science and Technology,Turkey
E-mail: zafer.utlu@gedik.edu.tr ; selenay.onal@hotmail.com

Abstract. In this study, waste heat was evaluated and examined by means of thermo-photovoltaic systems with the application of energy production potential GaSb cells. The aim of our study is to examine GaSb cell technology at high temperature waste heat. The evaluation of the waste heat to be used in the system is designed to be used in the electricity, industry and iron and steel industry. Our work is research. Graphic analysis is done with Matlab program. The high temperature waste heat graphs applied on the GaSb cell are in the results section. Our study aims to provide a source for future studies. **Keywords:** Thermophotovoltaic, Electricity generation, GaSb cell, High Temperature, Waste Heat

1.Introduction
Waste heat is the low-energy heat generated by the work done in the system. Systems such as machines, ovens and stoves emit heat for the duration of their work [1,2]. Waste heat can be produced by evaluating in thermophotovoltaic (TPV) systems. The working temperature of thermophotovoltaic systems is in the range of 1000-1500 ° C. The waste heat at this temperature value is converted to electricity energy by passing through the system components heat source, selective emitter, filter and photovoltaic (PV) cell.
The discovery of TPV dates back to about 1956. Most literature references, MIT in 1956, also made the concept suggests a series of conferences during the Aigra TPV. [3, 4]. Industrial waste heat recovery using TPV conversion was proposed by Coutts at the end of 1990s [5-8]. In addition, at the end of the 1990s, basic research on the Near Field TPV (NF-TPV) started. Electric power since the early 2000s has accelerated the development of the bottom 10 W miniature TPV generator. These studies show that TPV applications are increasingly increasing, contributing greatly to energy conversion and productivity.
In this study, electricity production by thermophotovoltaic methods is investigated by using GaSb cell in the high waste heat temperatures.

2.Description of Termophotovoltaic System
Thermophotovoltaic systems are systems that generate heat energy and electric energy from high temperature waste heat and solar radiation [8-13]. The solar rays on the photovoltaic cell are absorbed by the cell and turn the heat energy into electrical energy. They operate in the same way as photovoltaic devices convert visible light (solar energy) into electricity. Unlike solar photovoltaics [12]. TPV systems can provide higher efficiency and higher output energy density due to the lower energy band gap and closer distance between the active area of the TPV diode and the emitter. Thermophotovoltaic system includes selective emitter, heat source, filter and a photovoltaic cell as indicated Figure 1. The heat source in the system conveys the heat energy to the selective emitter and the photovoltaic cell module converts it to the thermal energy electrical energy. This transformation is considered as an alternative to existing electricity generation. At the same time, the electric energy to be obtained is obtained from the waste heat from the production stage in industrial systems. This saves energy and cost. In addition, waste heat released to the environment is evaluated.
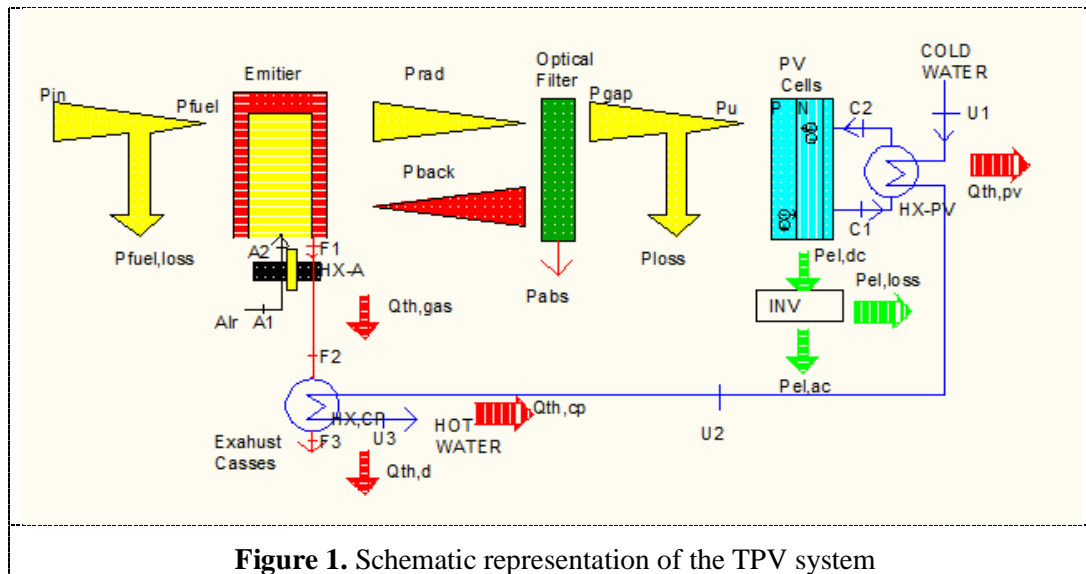
**Figure 1.** Schematic representation of the TPV system

3.Material and Methods

Thermophotovoltaic systems are systems that generate electricity from waste heat energy. Photovoltaic cells turn into thermal energy electrical energy. Analyses TPV high temperature waste heat values were obtained using GaSb cells. This analyses were done in MatLab program. The graphs obtained according to this analysis result are in our study.In the analysis made, TPV high temperature graphs were obtained using GaSb cell. The parameters used are; the temperature of the cell is the source temperature and the radiation temperature. With these graphs, energy efficiency, filling factor, effect of open circuit voltage and short circuit current values are determined.
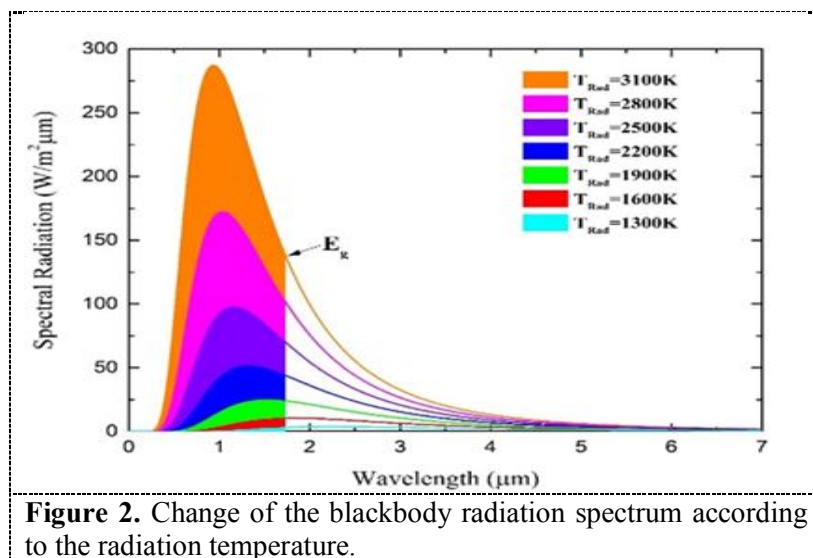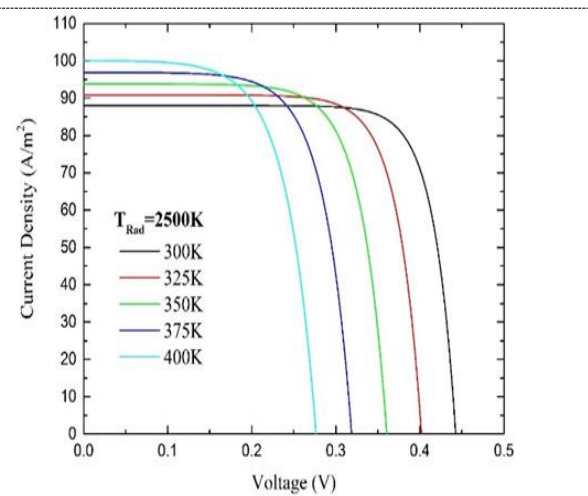

Figure 2. Change of the blackbody radiation spectrum according to the radiation temperature.

Figure 2 shows the change of the black body radiation spectrum at different wavelengths depending on the changing radiation temperature. For example, at a radiation temperature of 3100 K, the spectral radiation at 1 μm wavelength is approximately 280 W / m² μm, while it drops to approximately 100 W / m² μm at 2 μm wavelength. In this case, as the wavelength increases, the spectral radiation decreases.
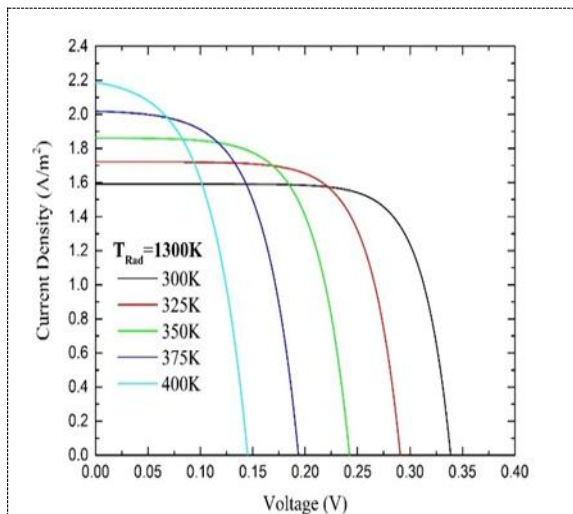
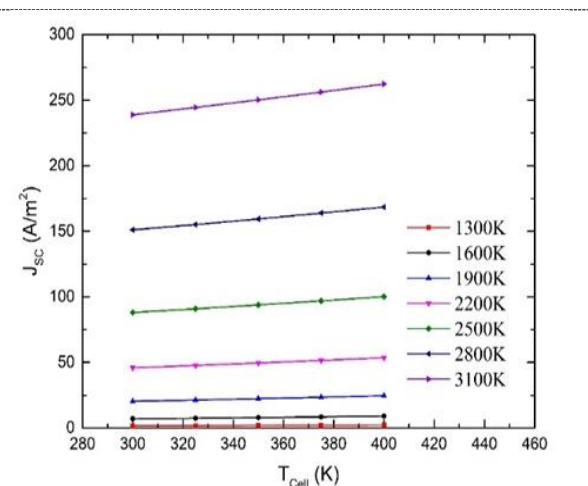| **Figure 3.** . Dependent on cell temperature for different current density - Voltage graph for Tradiation = 1300K. | **Figure 4.** Dependent on cell temperature for different current density - Voltage graph for Tradiation = 2500K. |

Figure 3 shows current densities at different cell temperatures at 1300 K radiation temperature versus varying voltage values. For example, at 400 K cell temperature, when the voltage value is 0.05 V, the current density is 2.2 A / m² whereas when the voltage value is 0.10 V, the current density drops to 1.7 A / m². In this case, as the voltage increases, the current density decreases. Figure 4 shows current densities at 2500 K radiation temperatures versus varying voltage values at different cell temperatures. For example, at 375 K cell temperature, when the voltage value is 0.1 V, the current density is about 97 A / m² whereas when the voltage value is 0.3 V, the current density drops to about 45 A / m². In this case, as the voltage increases, the current density decreases.
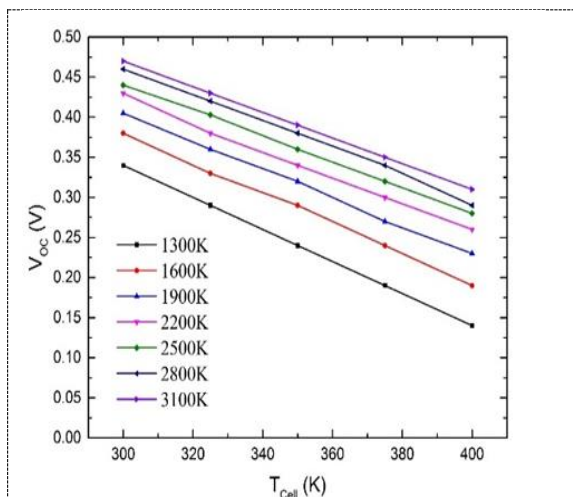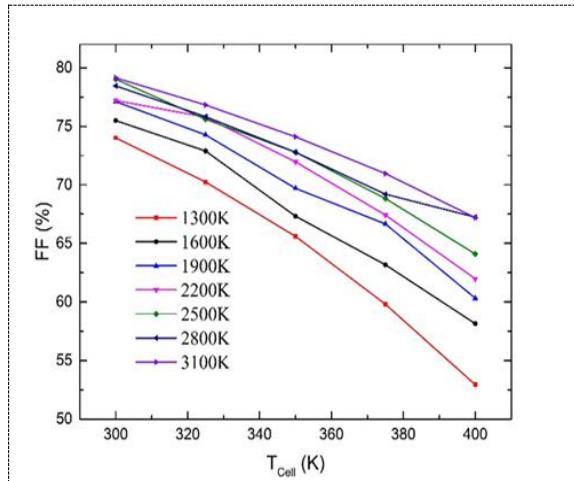

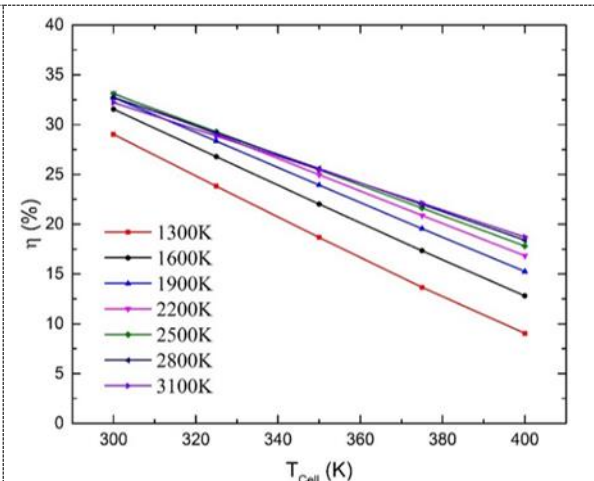| **Figure 5.** Tcell-Voc graph depending on the changing radiation source | **Figure 6.** Tcell-Jsc graph depending on the changing radiation source temperatures |

Figure 5 shows the relationship between cell temperature and open-circuit voltage, depending on the changing source temperature. For example, when the cell temperature is 300 K at 1900 K source temperature, the open circuit voltage is 0.4 V while the cell temperature is 400 K, the open circuit voltage decreases to 0.25 V.In this case, as the cell temperature increases, the open circuit voltage decreases. Figure 6 shows the relationship between cell temperature and short-circuit current depending on the changing source temperature. For example, when the cell temperature is 300 K at a

source temperature of 2500 K, the short circuit current is about 80 A / m² while when the cell temperature is 400 K, the short circuit current is about 100 A / m². In this case, it is observed that the short circuit current rises as the cell temperature increases.

Figure 7. Cell-to-FF graph depending on varying radiation source temperatures

Figure 8. Cell- η graph based on varying radiation source temperatures.

Figure 7 shows the relation between cell temperature and filling factor depending on the changing source temperature. For example, when the cell temperature is 300 K at 1300 K source temperature, the filling factor is about 75% while when the cell temperature is 400 K, the filling factor is about 53%. Figure 8 shows the relation between cell temperature and energy consumption depending on the changing source temperature. For example, at a source temperature of 1300 K, when the cell temperature is 300 K, the energy yield is about 30% while when the cell temperature is 400 K, the energy yield drops to about 10%. In this case, as the cell temperature increases, the energy efficiency decreases.

4. Conclusion

The main conclusions drawn from present study may summarize as follows;

• The change of the black body radiation spectrum at different wavelengths depending on the changing radiation temperature were examined. The highest spectral radiation was obtained at 3100 K source temperature.

• The current densities at different cell temperatures at 1300 K radiation temperature versus varying voltage values were analyzed.

• The highest starting current density was 2.2 A / m² at 400 K source temperature, while the lowest starting current density was 1.6 A / m² at 300 K source temperature.

• It has been determined that GaSb TPV cell applications can be applied to industrial systems in the direction of the obtained data, provide energy efficiency and provide an alternative to electricity generation.

References

[1] Utlu Z 2015 Investigation of the potential for heat recovery at low, medium and high stages in the Turkish industrial sector (TIS) *Energy* **81**: 394-405.

[2] Utlu Z and Hepbaşlı A 2007 A Review and assessment of the energy utilization efficiency in the turkish industrial sector using energy and exergy analysis method *Renew. Sustainable Energy Rev.* **11(7)** 1438-1459.

[3] Mustafaa K F, Abdullahb S, Abdullaha M Z and Sopianb K 2017 A review of combustion-driven thermoelectric (TE) and thermophotovoltaic (TPV) power Systems Renew. *Sustainable Energy Rev.* **71**:572–584.

[4] Steinhuser A, Hille G, Kugele R, Roth W and Schulz W 1999 Photovoltaic-hybrid power supply for radio network components *In Telecommunication Energy Conf, INTELEC'99. The 21st International* (p. 142).

[5] Bianchi M, Ferrari C, Melino F and Peretto, A 2012 Feasibility study of a Thermo-Photo–Voltaic system for CHP application in residential buildings *Applied Energy* **97**:704-13.

[6] Stone KW, Chubb DL, Wilt DM and Wanlass MW. 1996 *2nd NREL Conf. on Thermophotovoltaic generation of electricity* (AIP Conf. Proc. vol 358) p 198.

[7] Durisch W, Grob B, Mayor JC, Panitz JC and Rosselet A 1999 *4th NREL Conf. on Thermophotovoltaic generation of electricity* (AIP Conf. Proc. vol 460) p 403.

[8] Nelson RE 1996 *2nd NREL Conf. on Thermophotovoltaic generation of electricity* (AIP Conf. Proc. vol 358) p 221.

[9] Qiu K and Hayden ACS 2012 Development of a novel cascading TPV and TE power generation system *Applied Energy* **91**, 1: 304-308.

[10] De Pascale A, Ferrari C, Melino F, Morini M and Pinelli, M 2012 Integration between Thermo-Voltaic generator and an Organic Rankin Cycle *Applied Energy* **97**:695–703.

[11] Barbieri E, De Pascale A, Ferrari C, Melino F, Morini M, Peretto A and Pinelli M 2012 Performance evaluation of the integration between a Thermo-Photo-Voltaic generator and an organic Rankin cycle *J Eng Gas Turbine Power* **134**, 10:1-11.

[12] Utlu Z and Parali U 2013 Investigation of the potential of thermophotovoltaic heat recovery for Turkish   industrial sector *Energy Convers.Manag*. **74**:308–322.

[13] Utlu Z, Parali U and Gültekin Ç. Investigation of applicability of thermophotovoltaic technologies in the iron and steel sector *Energy Technology* DOI: 10.1002/ente.201700607