Performance evaluation of a hybrid CHP TPV microgenerator

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Abstract: This paper presents a practical implementation of a solar thermophotovoltaic (TPV) micro generator system. The system presented in the paper comprises a cylindrical shaped emitter (made of copper coated with Ni), and an hexagonal-shaped air-cooled (cooling is done with the metallic projections known as fins) TPV generator comprising --- Si TPV cells, which is surrounding the cylindrical emitter. This paper focuses on the development of TPV cell arrays, the estimation of the temperature achieved by the cylindrical emitters operated under controlled microflame application , and the evaluation of the full system performance under real indoor flame conditions. From the system characterization, we have measured short-circuit current densities up to 0.95 mA/cm^2, electric power densities of 67 mW/cm . In this thesis a TPV system is designed and developed in the laboratory of Rabindranath Tagore university and experimentation is carried out in the winter season which falls during the 1st December to 30th December 2018.

Keywords—Micro-thermophotovoltaic systems; Electric power densities; emitters;curren densities.

1. INTRODUCTION

The TPV system is a cogeneration of heat system in which the waste heat is utilized and recovered the energy from it. So the system is beneficial in the following aspects:

(*i*) It is becoming a dual system as the heat producing and waste heat utilizing in the power generation system so it is providing the high fuel utilization factor ≈1,

(*ii*) Noise levels is minimized,

(*iii*) Maintenance is easy due to the absence of dynamic parts in the system. and

(iv) Flexible for various fuels like; fossil fuels (natural gas, oil, coke, etc.) domestic wastes, nuclear fuels, etc; Solar insolation can be concentrated through parabolic trough or concentrators may also be used as a TPV heat source [3,4,5]. A TPV system produces a very low or nil amount of pollutant emissions in the terms of particulates emittants of carbon monoxide and Nitrous oxide. The main application of TPV system is in the devices where the preheating air or gas is required though it is generally keyed with combustion devices such as domestic boilers. Some more applications of TPV system can be discussed here as in the automobile sector in case of hybrid vehicles [6], or in the industries where high temperatures is to be required [7]. So the TPV system can be recognized and used as a small generators [9, 13], waste heat co-generation systems [14], combined thermal power plants and solar power plants [15], on grid system [16] independent device [17]. Other literature shows that the TPV generator can be equipped with the thermo-electric power systems [18] in the military and space sectors [19-23].

The electrical efficiency of a TPV generator can be written as:

$$\eta_{EL,TPV} = \eta_{CC} \cdot \eta_{RAD} \cdot \eta_{GAP} \cdot \eta_{F} \cdot \eta_{VF} \cdot \eta_{PV} \cdot \eta_{dc/ac}$$

where:

η_{CC}: combustion efficiency;

ηRAD: radiant efficiency;

ηGAP: spectral efficiency;

ηF: filter efficiency;

ηVF: view factor efficiency

$\eta Cell$: cell efficiency

$\eta inverter$: Inverter efficiency.

In this paper two conditions are taken into consideration to evaluate the described system performance firstly, When the selective emitter with one seed layer of Ni is applied and second is with two seed layer of Ni is applied. These two conditions are segregated into four cases and all four cases likewise;(i)When the microflame burner is one 12th open,(ii) When the microflame burner is one 15th open,(iii) When the microflame burner is one 18th open,(iv) When the microflame burner is one 27th open etc. are discussed and in all 4 cases for each conditions different flow rates are set which could be able to give maximum electrical power output with the minimum thermal power utilization.

TPV application was made on the industrial steel industry. Utilizing this industry's high-temperature waste heat, which has a significant share in Turkey, electricity is generated. Waste heat source, selective spreader, filter and cell are necessary for electricity production. These cells absorb photons from the emitter and convert them into thermal energy electrical energy. In the study, the effects of cell temperature, cell type, radiator temperature parameters on cell efficiency were examined in TPV systems.

2.Description of system

A prototype micro-TPV system with micro-combustor is shown in figure 5.10. The butane mixture is combusted in the micro-combustor. When the wall of the micro-combustor (emitter) is heated to a sufficiently high temperature, it emits many photons. When photons with an energy greater than the bandgap of the PV cells impinge on the PV array, they produce free electrons and, consequently, electrical power. Compared to conventional combustors, a microcombustor is more highly constrained by inadequate residence time for complete combustion and high rates of heat transfer from the combustor. In this work, butane is chosen as the fuel because of its original high heating value, fast diffusion velocity, short reaction time and high flame speed [15].

For micro-TPV applications, the desired output is a high and uniform temperature along the wall of the microcombustor. Compared to conventional macro-TPV systems, the micro-TPV systems feature a much higher power density per unit volume due to the high surface-to-volume ratio.

The major challenge in micro-combustor design is to keep an optimum balance between sustaining combustion and maximizing the heat output. A high surface-to-volume ratio is very favourable to the output power density per unit volume. However, a high heat output will affect the stable combustion in the micro-combustor. To verify the feasibility of microcombustion and optimize the design of the micro-combustor,

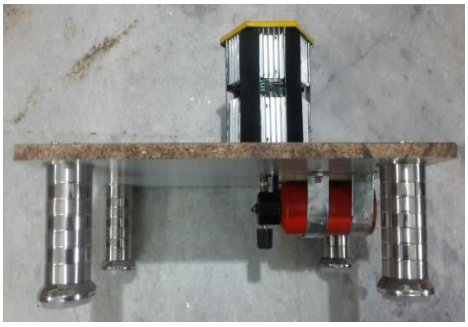


Fig. 2 (a) Front view

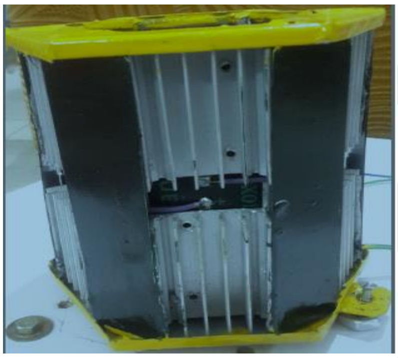


Fig.2 (b)Front View showing Fins

3.System Modelling Dimensional modeling of the experimental setup through CAD

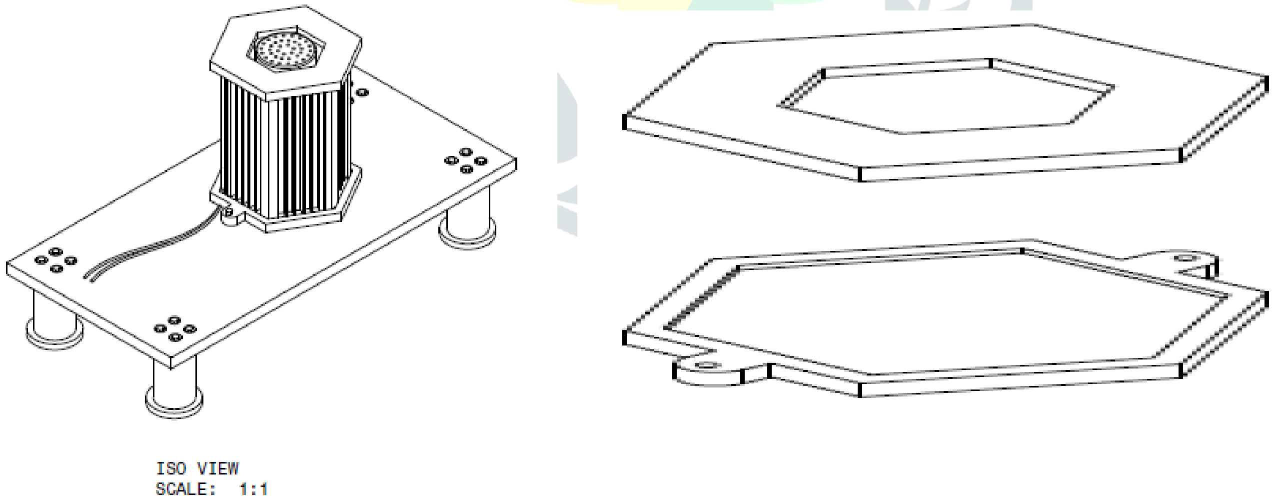


Fig.3.1 (a) Experimental set up Isometric View (b) Upper hexagonal part of the housing

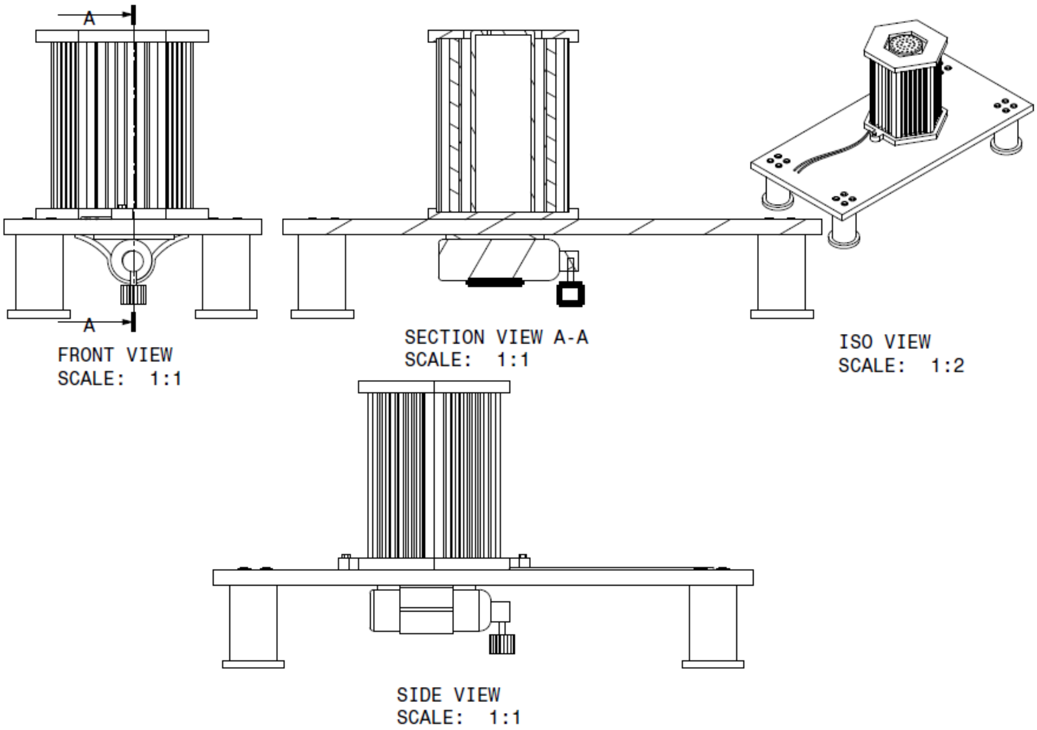
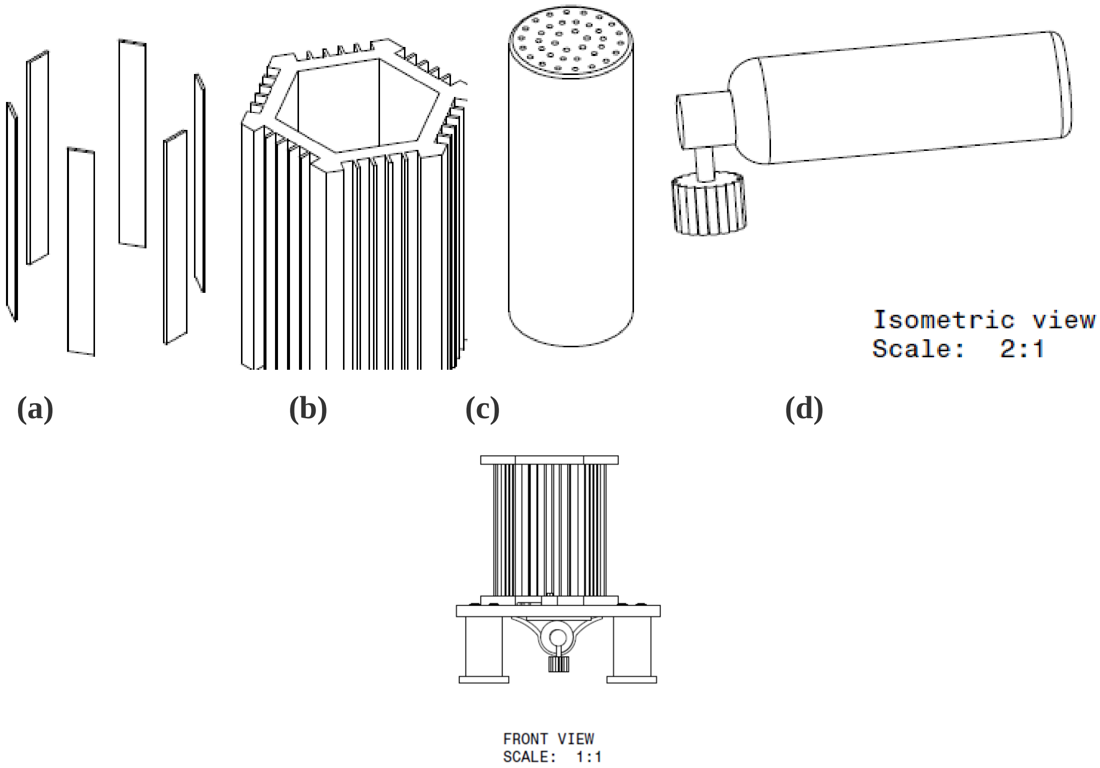


Fig.3.2 Various view of Experimental set up Lateral and Top view



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

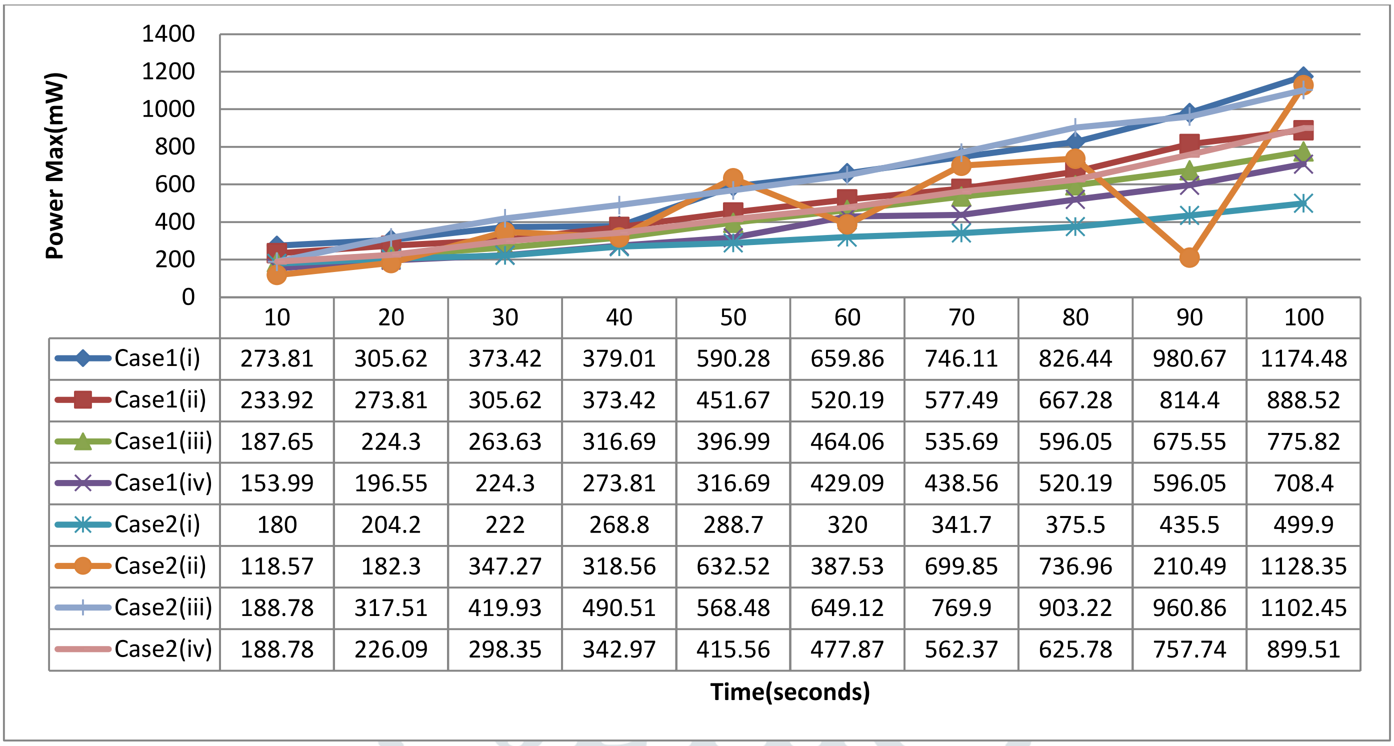
(d)

Fig. 3.3(a) PV panel (b)Fins(c)Cylinder for gas(d) Front view of the set up

4.Results and Discussions

In this paper an analysis on TPV high temperature waste heat values which are obtained using Si cells. This analysis was done in Microsoft Excel and Sigma plot software for the accuracy purpose On the basis of the analysis some useful results are obtained. Graphs obtained from this analysis are the major source of our research. The analysis made, TPV high temperature graphs are obtained using Si cells. Parameters which are to be used as follows:

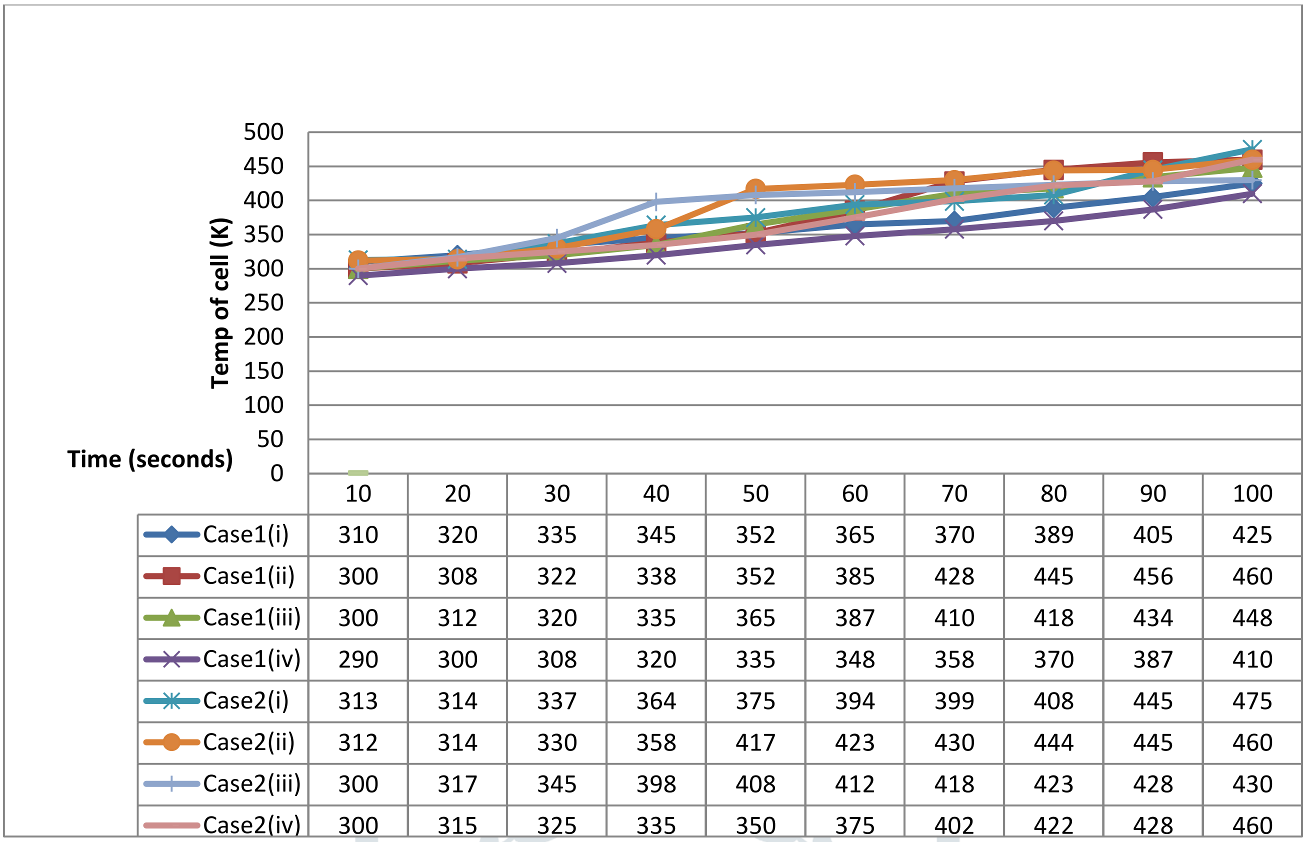
- The temperature of the cell which is the source temperature and the radiation temperature.
- Electrical efficiency
- Filling factor
- Open circuit voltage and short circuit current
- Max. power output
- Flow rate
- Thermal power utilization
- Two conditions are taken into consideration to evaluate the described system performance firstly, When the selective emitter with one seed layer of Ni is applied and second is with two seed layer of Ni is applied. These two conditions are segregated into four cases and all four cases likewise;(i)When the microflame burner is one 12th open,(ii) When the microflame burner is one 15th open,(iii) When the microflame burner is one 18th open,(iv) When the microflame burner is one 27th open etc. are discussed and in all 4 cases for each conditions different flow rates are set which could be able to give maximum electrical power output with the minimum thermal power utilization.
- Comparison of the performance parameters of TPV micro-generators at various flow rate for all four cases under 2 conditions are discussed in the figures 4.1 and 4.2. Figure 4.3 shows the variation of Electrical power output for all the four cases at different flow rate it is observed from the figure that at the flow rate one for the case 1 electrical power is max. at the max temperature but the graph shows that it does not vary linearly it varies from the lowest to the highest then becomes low then again increased. There is only case 2 where at the flow rate 3 electrical power follows the linear pattern which increases with the increase in temperature and a little increase is shown at each increment of temperature of cell temperature. In the case 1 initial temp. is taken as 300 K after each 10sec interval electrical power is computed and it is found 273.81mW and a max. value of 1174.4mW.In case 3 of condition 2.
- At the flow rate of 3 which is equal to $1.0264X10^{-6}$l/s. power varies from 1188.78 mW to a max value of 1102.4mW. Although the power output is low at the max. but in this case but the linear arrangement of the graph thermal power utilization for the conversion of electrical power and temperature of cell make the system useful for the case.
- Therefore, the tendency of Voc to decrease and Isc to increase with increasing temperature in the solar cells results in a decrease in the efficiency with increasing temperature. The performance of cells for case (III) gives the best agreement between the calculated and available theoretical and experimental data for solar cells made fromSi. case (III) seems to be more appropriate at 475 K.



	10	20	30	40	50	60	70	80	90	100
Case1(i)	273.81	305.62	373.42	379.01	590.28	659.86	746.11	826.44	980.67	1174.48
Case1(ii)	233.92	273.81	305.62	373.42	451.67	520.19	577.49	667.28	814.4	888.52
Case1(iii)	187.65	224.3	263.63	316.69	396.99	464.06	535.69	596.05	675.55	775.82
Case1(iv)	153.99	196.55	224.3	273.81	316.69	429.09	438.56	520.19	596.05	708.4
Case2(i)	180	204.2	222	268.8	288.7	320	341.7	375.5	435.5	499.9
Case2(ii)	118.57	182.3	347.27	318.56	632.52	387.53	699.85	736.96	210.49	1128.35
Case2(iii)	188.78	317.51	419.93	490.51	568.48	649.12	769.9	903.22	960.86	1102.45
Case2(iv)	188.78	226.09	298.35	342.97	415.56	477.87	562.37	625.78	757.74	899.51

Fig.4.1 Comparison of Max. Power out put for CaseI and CaseII at various flow rate

Comparison of temperature of the PV cell for case I and case II at various flow rates are compared in the fig.4c.1.In case II at the flow rate 3 temperature is increasing linearly and achieves the max value which shows at minimum utilization of thermal power to obtain the maximum power out put temperature must remain in the limit of band gap energy all the heat energy must be absorbed to emit the electron from the PV cell of the TPV system as we applied the selective emitter to get the good combination of temperature and band gap energy.



	10	20	30	40	50	60	70	80	90	100
Case1(i)	310	320	335	345	352	365	370	389	405	425
Case1(ii)	300	308	322	338	352	385	428	445	456	460
Case1(iii)	300	312	320	335	365	387	410	418	434	448
Case1(iv)	290	300	308	320	335	348	358	370	387	410
Case2(i)	313	314	337	364	375	394	399	408	445	475
Case2(ii)	312	314	330	358	417	423	430	444	445	460
Case2(iii)	300	317	345	398	408	412	418	423	428	430
Case2(iv)	300	315	325	335	350	375	402	422	428	460

Fig.4.2 Comparison of Cell temperature for CaseI and CaseII at various flow rate

5.Conclusion

The TPV system is a promising technology which can be a future application for various thermal industries as in the system waste heat is to be utilized and recovered and turn into the useful electrical power out put for the system we have used very small system to observed the micro changes in the performance parameters.

TPV system design is complex, but has several advantages besides directly converting heat radiation into electricity. A practical advantage is, that these systems are modular and lightweight. Therefore, existing systems can be expanded or adapted to the needs. Furthermore, they have a lifetime up to 25 years and need only little maintenance. They operate silent and emission-free as well as steadily in terms of intensity, spectrum, and angle of radiation as well as PV cell temperature. Moreover, TPV systems can be used as power sources on their own, as well as in combined heat and power (CHP) generation systems. [8,22,23,24].

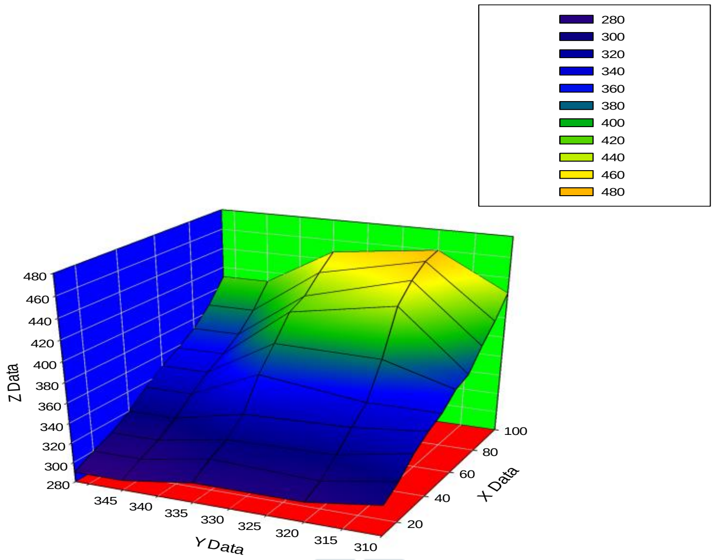


Fig.4.3 Temperature distribution on the upper face of the cell

Comparing TPV to solar PV, TPV has potentially higher efficiency and heat source flexibility, although, lower heat source temperatures result in a difficulty to achieve high efficiencies. On the other hand, the heat source and the PV cell are much closer to each other in TPV (≈1-10 cm) compared to the distance to the sun (≈1.5 × 1010 m). This fact makes much higher power densities possible, which can be around 5-60 W/cm^2 compared with 0.1 W/cm^2 for solar cells. Another difference of PV and TPV is that TPV only converts thermal radiation in contrast to the whole spectrum of the sunlight. Therefore, PV cells that cover a higher wavelengths spectrum are needed for TPV. Moreover, the emitter of a TPV system can be controlled and thus, helps to increase the system efficiency. [22]

The research has been conducted under both the experimental and the theoretical point of view. The main researches activities were directed through the developments of the TPV components (with a particular attention to the emitter and to the PV cells) but also to the analysis of the TPV generator performance in CHP configuration with reference to the domestic scenario.

TPV application was made on the industrial steel industry. Utilizing this industry's high-temperature waste heat, which has a significant share in Turkey, electricity is generated. Waste heat source, selective spreader, filter and cell are necessary for electricity production. These cells absorb photons from the emitter and convert them into thermal energy electrical energy. In the study, the effects of cell temperature, cell type, radiator temperature parameters on cell efficiency were examined in TPV systems.

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