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Research paper

Thermoelectric generator electrical performance based on temperature of thermoelectric materials

S. Parveen [1] *, S. Victor Vedanayakam [2], R. Padma Suvarna [3]

[1] Ph.D. (Research Scholar), JNTUA, Anantapur, Andhra Pradesh, India
[2] Department of Physics, Madanapalle Institute of Technology and Science, Madanapalle, Andhra Pradesh, India
[3] Department of Physics, JNTUA, CEA, Anantapur, Andhra Pradesh, India
**Corresponding author E-mail: parveen.atp@gmail.com*

Abstract

In space applications, the radioisotope thermoelectric generators are being used for the power generation. The energy storage devices like fuel cells, solar cells cannot function in remote areas, in such cases the power generating systems can work successfully for generating electrical power in space missions. The efficiency of thermo electric generators is around 5% to 8% . Bismuth telluride has high electrical conductivity (1.1 x 105S.m /m2) and very low thermal conductivity (1.20 W/ m.K). A Thermoelectric generator has been built up consisting of a Bi2Te3 based on thermoelectric module. The main aim of this is when four thermoelectric modules are connected in series, the power and efficiency was calculated. The thermoelectric module used is TEP1-1264-1.5. This thermoelectric module is having a size of 40mmx40mm. The hot side maximum temperature was 1600C where the cold side temperature is at 400C. At load resistance, 15Ω the maximum efficiency calculated was 6.80%, at temperature of 1600C. The maximum power at this temperature was 15.01W, the output voltage is 16.5V, and the output current is 0.91A. The related and the corresponding graphs between efficiency, power, output voltage, output current was drawn at different temperatures. The efficiency of bismuth telluride, thermoelectric module is greater than other thermoelectric materials.

Keywords: *Thermoelectric Power Generator; Thermoelectric Materials; Load Resistance; Efficiency.*

1. Introduction

Bismuth telluride and its alloys are used as thermoelectric materials for thermoelectric generator because of the material depends upon the electrical conductivity, Seebeck coefficient and thermal conductivity properties. For a thermoelectric materials, the efficiency of it is given by [1-6] the formula,

$$ZT = S^2 \sigma T / K \quad (1)$$

Where σ is an electrical conductivity, K is the thermal conductivity S is the Seebeck coefficient at temperature T. The ZT value depends upon the Seebeck coefficient and an electrical conductivity. As Seebeck coefficient increases, the ZT value also increases [7-11]. Bismuth telluride alloys [12-13] are the best thermoelectric materials at room temperature. The electrical conductivity, Seebeck coefficient increases but the thermalconductivity decreases. The thermoelectric figure – of –merit, ZT had a great improvement with the property of thermoelectric material, in the range of 127^0C to 527^0C [14-15] for the generation of power.

2. Electrical performance of different thermoelectric materials

At room temperature, Bismuth telluride and its alloys are the most important thermo electrical materials and are used for solid-state refrigeration and for power generation. The band gap of bismuth telluride is 0.16eV. For the materials of bismuth telluride and bismuth selenide the best performing materials at room temperature and the thermo electrics with a temperature independent figure of merit , ZT is between 0.8 and 1.0 for these materials. Therefore around 300 K, these materials are suitable for solid state refrigeration applications. The ZT value of n-type and p-type bismuth telluride alloys is equal to unity up to a temperature of 500K. Therefore for thermoelectric refrigeration bismuth telluride alloys are used as materials. For different thermoelectric materials the electrical properties are shown in table 1 below.

Table 1: Electrical Properties of Different Thermoelectric Materials:

Thermo electric materials	Density	Electrical conductivity	Band gap	Seebeck Coefficient
Bi2 Te3	7.74 g/cm3	1.1x105 s/m	0.21ev	170µv/k
PbTe	8.16 g/cm3	741 to 10905s/m	0.25ev	-26µv/k to -215µv/k
Sb2 Te3	6.50 g/cm3	1.65w/m-k (at 350C)	0.21ev	72µv/k 165µv/k (at 2000c)
BiSb	7.70 g/cm3	7.7 x105 s/m (at 200C)	0.32eV	-140µv/k (at 80K)
PbBi	10.44 g/cm3	4 w/m-k	0.20eV	-110µv/k

Note that, when the temperature difference increases the open circuit voltage is increased because of temperature difference increase although the Seebeck coefficient decreases. So the higher temperature difference across TEG higher open circuit voltage can be

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reached. From the above analysis, it can be seen that the temperature difference has an effect on Seebeck coefficient, which also means the Seebeck coefficient is not constant. Therefore, for further analysis the temperature of the hot end and cold end is fixed constant, respectively. Above room temperature, PbTe is a material with good thermo electric properties . Thermo electric materials of both p-type and n-type PbTe are used for practical applications. The materials of combinations of lead based materials like PbTe, PbSe, PbS show high ZT values and high performance at room temperature. For several NASA space missions, since 1960s PbTe based material is used. For both n-type and p-type materials the maximum ZT values are of nearly equal to 1.4. For homogeneous PbTe materials , the enhancement of figure of merit has been achieved and the ZT reaches a value of nearly 1.8 [16-17] . In research laboratories, the measurement of the electrical resistivity and Seebeck coefficient could be performed accurately.

3. Electrical performance of TEG

The performance of thermoelectric generator increases the temperature difference on both sides like cold side and hot side increases. As heat is increased in thermoelectric legs , their electrical performance increases. From equation [1.1], ZT is around [1] for thermoelectric devices made of bismuth telluride or tin telluride alloys at room temperature applications, and at higher temperature applications. With the help of these thermoelectric modules, which are made of many p-type and n-type pellets and they can be connected thermally in parallel and electrically in series. Depending upon temperature ranges the thermoelectric devices are classified as shown in Table 2

Table 2: Thermo Electric Materials Temperature Classification

	Low Temperature Materials (27^0C - 177^0C)	Intermediate Material (27^0C - 577^0C)	High Temperature Material (27^0C - 1027^0C)
Materials Combinations	Bi	Pbte	Sige
Other Combinations	Sb,Te,Se	Pbte	Sige

4. Experimental details

The thermoelectric module TEP1 – 1264- 1.5 will be the power module designed and manufactured for converting heat source into electrical power. Depending upon the temperature difference across the module the thermoelectric module generates an electricity. The efficiency and the output power will be increasing , when the temperature difference between the thermoelectric module is larger for converting heat energy into electrical power. This module is shown in Fig 1 below.

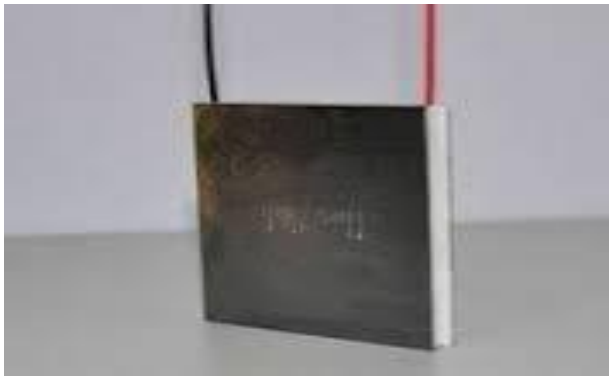


Fig. 1: The Thermoelectric Module TEP1 -1264-1.5.

The thermoelectric module TEP1-1264-1.5 is bismuth telluride based thermoelectric generator. The size of this module is 40mm x 40mm and the thermo electric module will generate the dc electricity as long as there is a temperature difference across the module. The experimental values when four thermoelectric generators are connected in series, the output voltages, output currents and power generated at cold side temperature of 400C and also the calculated the efficiency are shown in shown in Table:3 at load resistance of 15Ω.

Table 3:

S.NO	Hot side Temperature (^{0}C)	Output voltage (V)	Output current (A)	Power (W)	Efficiency (%)
1.	55	6.2	0.38	2.35	0.93
2.	60	6.8	0.40	2.72	1.23
3.	65	7.4	0.42	3.10	1.53
4.	70	8.5	0.44	3.74	1.83
5.	75	9.3	0.45	4.18	2.13
6.	80	9.8	0.46	4.50	2.42
7.	85	10.5	0.48	5.04	2.71
8.	90	11.6	0.50	5.8	2.97
9.	95	12.4	0.52	6.44	3.24
10.	100	12.7	0.54	6.85	3.57
11.	105	13.2	0.56	7.39	3.85
12.	110	13.6	0.63	8.56	4.13
13.	115	14.1	0.69	9.72	4.41
14.	120	14.4	0.72	10.36	4.68
15.	125	14.9	0.75	11.17	4.96
16.	130	15.2	0.78	11.85	5.23
17.	135	15.6	0.81	12.63	5.62
18.	140	15.9	0.84	13.35	5.76
19.	145	16.0	0.87	13.92	6.02
20.	150	16.3	0.89	14.50	6.28
21.	155	16.4	0.90	14.76	6.54
22.	160	16.5	0.91	15.01	6.80

From Table:3 as temperature increases the maximum current drawn will be 0.54A, and the maximum power that can be calculated as , output voltage is multiplied by the output current and therefore we got it as 6.85W at an output voltage of 12.7V . The efficiency can be calculated by

$$\eta = \frac{T_H - T_C}{T_H} X \frac{[\sqrt{1} + Z\,T_{avg}] - 1}{[\sqrt{1} + Z\,T_{avg}] + \frac{T_C}{T_H}} \quad (2)$$

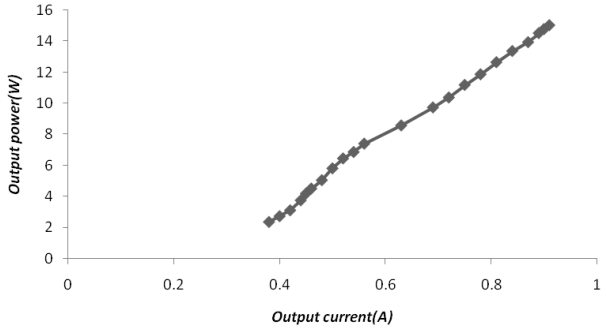
In addition, Z Tavg. is calculated from equation, [1.1]
Which is given by,

$$Z\,T_{avg.} = S^2 \sigma\, T\, /K$$

Where ZT_{avg}. is the Figure-of-merit of thermoelectric, S is the Seebeck Coefficient,σ is the electrical conductivity , K is the thermal conductivity. For the thermoelectric module, TEP1- 1264 – 1.5, Bi_2Te_3 material T_{avg}.is the average temperature of TH and TC. T_H is the hot side temperature for the first reading will be 550 C; TC is the cold side temperature will be 400 C. The values of σ = 1.1 x 10^5 s/m, S = 170μV/K, K = 1.20 W/m K. After substituting these values in equation [1.4] we can get the ZT_{avg}. This ZT_{avg}.is substituting in equation [1.3], the efficiency was calculated at that temperature. In a similar way, the other efficiency calculations can be made. The maximum efficiency was 6.80% at temperature of 160^0C. The corresponding graphs for efficiency, output current, output voltage and power can be drawn. The related graphs are drawn below at different temperatures from 55^0C to 160^0C.

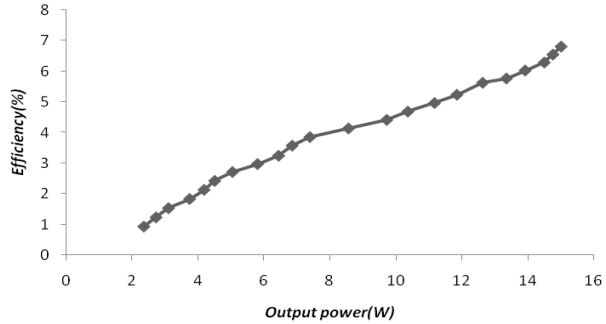
5. Results and discussions

At different temperatures the corresponding graphs drawn and corresponding efficiency was calculated.



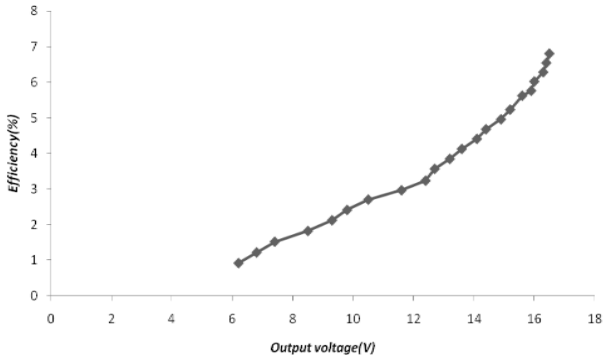
Graph. 1: Output Power as a Function of Output Current.

From graph:1 at different temperatures , the output current and output power can be shown . The maximum current was 0.91A and the maximum power got is 15.01W. In this case as the current increasing, the output power also increasing.



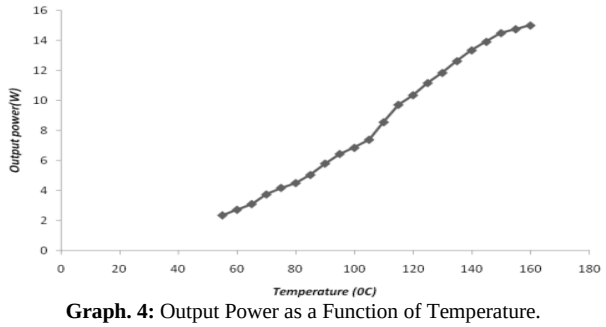
Graph. 2: Efficiency as a Function of Output Power.

From Graph 2: The efficiency of a thermoelectric material is increasing with output power and the maximum efficiency is 6.80% at the maximum output power of 15.01W at different temperatures starting from 550 C to 1600 C. At first the efficiency is 0.93% for the output power of 2.35W.



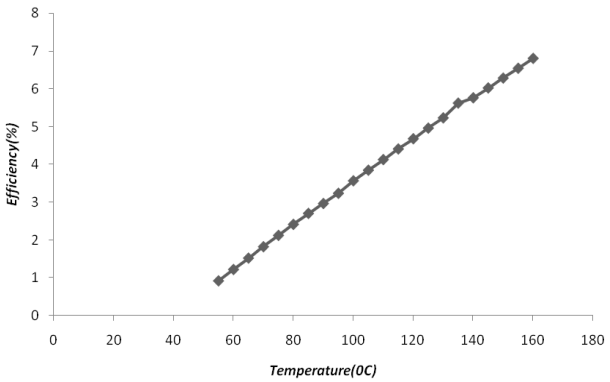
Graph. 3: Efficiency as a Function of Output Voltage.

Graph 3: is drawn between efficiency as a function of output voltage. From this graph at different temperatures, the efficiency and the output voltages are increasing and the maximum voltage is 16.5V, the efficiency will be 6.80%.



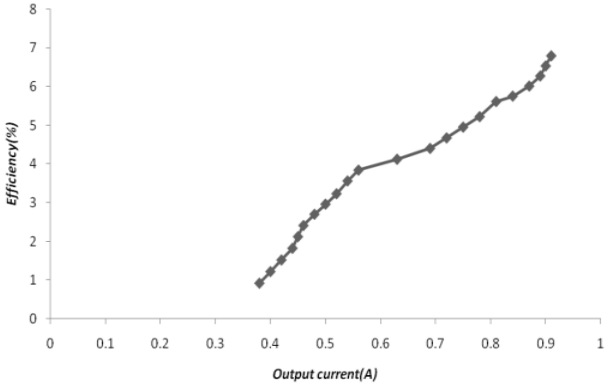
Graph. 4: Output Power as a Function of Temperature.

Graph 4: is drawn between Output power as a function of temperature. From this graph, the output power will be increasing at different temperatures. At 1600C the maximum power drawn is 15.01W. At hot side temperature of thermoelectric material, 550 C the output power is 2.35W.



Graph. 5: Efficiency as a Function of Temperature.

Graph. Five: is drawn between the efficiency of thermoelectric material as a temperature (0C), at different temperatures the efficiency is calculated. At a temperature of 550 C, the efficiency of thermoelectric material is 0.93%. From this graph as the efficiency is increasing, at different temperatures. At a temperature of 1600 C , the maximum efficiency will be 6.80%.



Graph. 6: Efficiency as a Function of Output Current.

Graph 6 represents the efficiency as a function of output current. At different temperatures, the efficiency and the output current will be increasing. At a temperature of 550C, the output current is 0.38A and the efficiency achieved is 0.93%. The maximum current is 0.91A and the maximum efficiency is 6.80% at temperature of 1600C.

6. Conclusions

In this paper, the thermoelectric module is TEP1-1264-1.5. At different temperatures, when four thermoelectric modules are connected in series, the efficiency was calculated in addition to the readings taken of output voltage, output current and power. The maximum efficiency achieved was 6.80%, at temperature of 1600C and the maximum power is 15.01W at a maximum output voltage of 16.5V. But at temperature of 550C, the efficiency is 0.93%, output power is 2.35W, output current 0.38A and the output voltage is 6.2V. When compared to PbTe module at 373K (1000 C), the efficiency of single module is 2.52%. The lead telluride has an efficiency of 6% in 500K to 900K. Therefore at different temperatures, the efficiency was increasing with power, output current and output voltage. The electrical performance of thermoelectric module, bismuth telluride was compared with other thermoelectric materials.

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