PERFORMANCE EVALUATION OF THE THERMOELECTRIC GENERATOR

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Abstract: *The energy produced by the thermoelectric generators is clean and it can be used for the niches application. The paper presents the characterization of the commercial Bi_2Te_3 thermoelectric generator in function of the temperature. The temperature difference between the two parts of the thermoelectric generator is increased using an additional thermoelectric device to heat the hot part, and an aluminum cooler for maintaining the cold part at quasi constant temperature. The I-V and the P-V characteristics of the thermoelectric element are measured at different temperatures. The maxim power, the Seebeck coefficient and the internal electric resistance are calculated. The software to control the devices, to perform the measurements and analyse the data is created.*

Keywords: *thermoelectric generator, Seebeck effect, maxim power, internal resistance*

1. INTRODUCTION

Nowadays it is very important to produce clean energy. There are many types of renewable energy which are mature: solar energy (photovoltaic and thermal energy), wind energy, geothermal energy, micro hydro power, etc. Other types of clean energy have also begun to be used, for example the energy produced by the piezoelectric element and the energy produced by the thermoelectric generator.

The thermoelectric devices can produce a small electric power by converting the thermal energy in electrical energy based on the Seebeck effect and the electrical energy in thermal energy based on the Peltier effect [1-3].

The applications of the thermoelectric devices are destined to cool or heat different things which are coupled at their hot or cold parts [4,5]. The thermoelectric generators can be used in different applications, such as active building envelope [6], heat recovery in automotive, battery charging [7], radioisotope power systems [8], spatial applications, in concentrated solar energy [9] and solar photovoltaic energy [10].

2. THE THERMOELECTRIC GENERATOR

The thermoelectric generator consists of a number of thermoelectric elements that are connected thermally in parallel and electrically in series. The series connection is necessary to increase the generated voltage. The thermal conductivity can be increased if the elements are connected in parallel [1,2]. The structure of the thermoelectric elements consists of: a p type semiconductor connected through a cooper plate with an n type semiconductor, which are placed between two ceramic plates, Fig.1.

The thermoelectric generator can be classified in function of the figure of merit, ZT [11]:

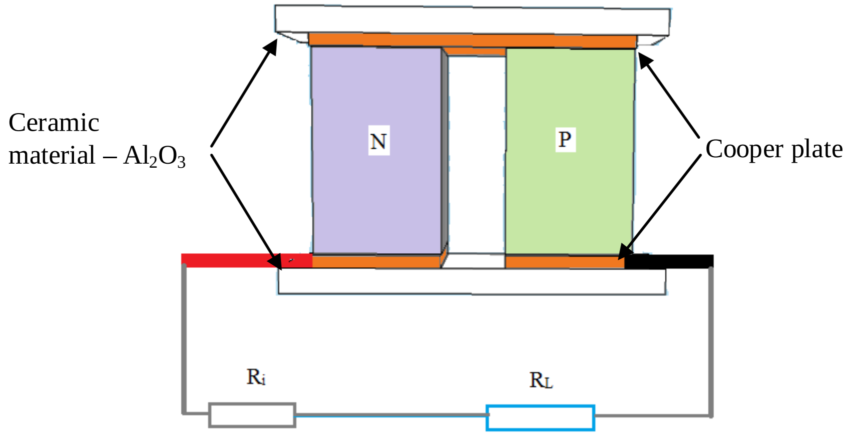


FIG. 1. The structure of the thermoelectric generator

- First generation – ZT < 1.3 and the efficiency of the thermoelectric generator is between 4% and 6%.
- Second generation – $1.3 \leq ZT \leq 1\ 8$ and the efficien cy of the thermoelectric generator is between 11% and 15%.
- Third generation – ZT > 1.8 and the estimated efficiency of the thermoelectric generator is greater than15%.

The equation which describes the figure of merit was discovered by Altenkirch in 1911 [11].

$$ZT = \frac{\alpha^2 \sigma}{k} T \tag{1}$$

where σ represents the electrical conductivity, k is the thermal conductivity and α is the Seebeck coefficient.

The efficiency of the thermoelectric generator function of the figure of merit can be calculated with the following equation (2):

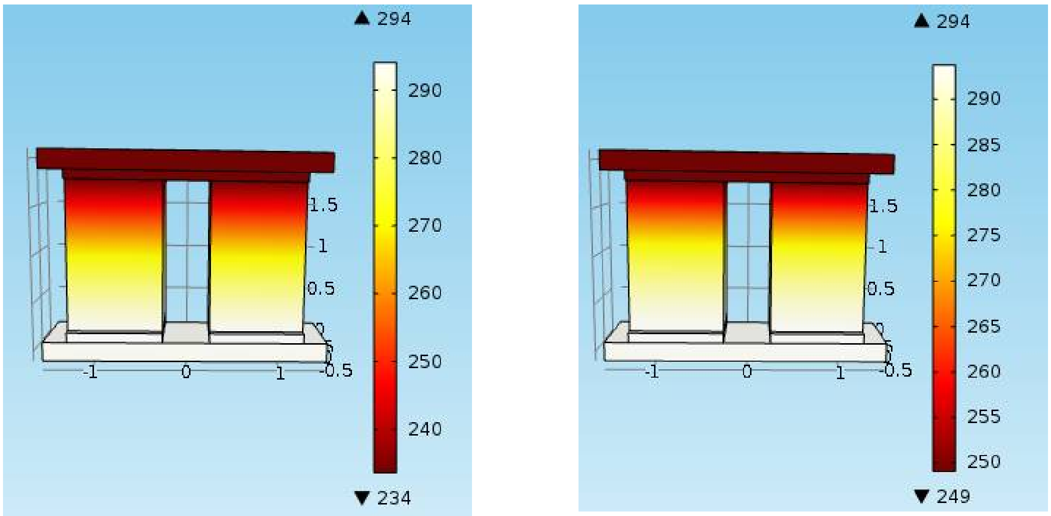
$$\eta = \frac{(T_h - T_c)}{T_h} \frac{\sqrt{1 + ZT_m} - 1}{\sqrt{1 + ZT_m} + \frac{T_c}{T_h}} \tag{2}$$

where the first factor of the ratio represents the Carnot efficiency, T_c is the temperature of the thermoelectric element's cold part, T_h is the temperature of the thermoelectric element's hot part and T_m is the average temperature between the T_h and T_c.

The Bi_2Te_3 thermoelectric generator is the most widely used due to the acceptable price, performance and low work temperature. The Bi_2Te_3 thermoelectric generator performance can be improved if it is combined with isomorphic compounds such as PbTe, GeTe and Sb_2Te_3 [12,13].

The temperature distribution in two thermoelectric devices, Bi_2Te_3 and PbTe when a potential by 0.1 V is applied is presented in Fig.2. The simulation was realized using the Comsol multiphysics program.

The thermoelectric generator generated a voltage when there is a temperature difference between the hot and cold parts. The voltage can be calculated using the power balance by equation (3) [14]:



(a) (b)

FIG. 2. The temperature distribution of the two types of thermoelectric generator (a) Bi_2Te_3 (b) PbTe

$$V = \alpha(T_h - T_c) - IR_i \tag{3}$$

where I is the current in the circuit and R_i is the internal resistance of the thermoelectric generator.

The circuit current can be obtained using the following equation (4) and $V=IR_L$:

$$I = \frac{\alpha(T_h - T_c)}{R_i + R_L} \tag{4}$$

where R_L is the load resistance, see figure 1.

Using the equation (5) the electric power generated by the thermoelectric generator can be calculated:

$$P = IV = R_L \frac{\alpha^2 (T_h - T_c)^2}{(R_i + R_L)^2} \tag{5}$$

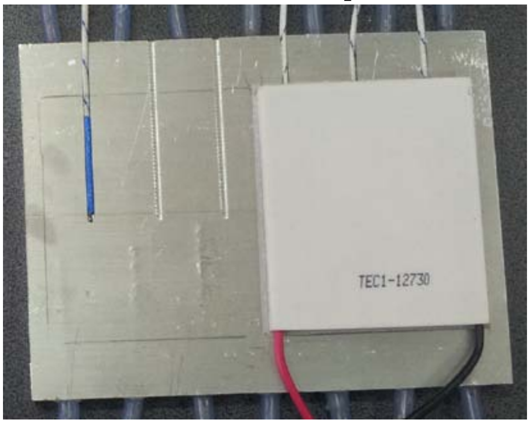
3. THE EXPERIMENTAL SET-UP

The current voltage characteristic, I-V, is an important tool to characterize the semiconductors, therefore it can be successfully used to analyzed the performance of the thermoelectric generator.

In this work, a commercial Bi_2Te_3 thermoelectric generator, with the dimensions of 6.2 cm/ 6.2 cm / 4.8 mm is analyzed function of the temperature difference between the hot and cold parts.

The temperature difference between the two parts of the thermoelectric generator is realized through maintaining the cold part at quasi constant temperature and increasing the temperature of the thermoelectric generator hot part.

The quasi constant temperature of the cold part is obtained through connecting it with 0.1 mm thermal adhesive tape at an aluminum block, Fig.3a, which is cooled with water.



(a)

(b)

FIG. 3. The thermoelectric generator's (a) cold part connected with aluminum block (b) hot part connected with other thermoelectric device

The water flow is monitored with a flowmeter and the water temperature is measured at three points: inlet and outlet of the aluminum block and water tank. The water flow can be changed by controlling the voltage drop on the water pump.

The increasing in temperature of the hot part is obtained by connecting it with 1 mm thermal adhesive tape with the other thermoelectric device, Fig.3b, which is connected at DC programmable power supply.

The I-V characteristics for the thermoelectric generator are measured using a simple electronic load built for this study and the NI cRIO integrated system. NI cRIO (National Instruments compact Reconfigurable Input Output) is an embedded platform which contains a real time processor used for communication and signal processing and a FPGA module that can be programmed by the user for high performance data processing at hardware level. The platform used in our setup is NI cRIO 9074 which has eight slots for connection with C Series I/O Modules which are hot swappable. For measuring the I-V characteristics the NI 9215 module was used which measures the voltage on the thermoelectric generator and the voltage on a resistor with known values for the determination of the current. The NI 9269 module was used for the electronic load and the water pump control.

The temperatures of the thermoelectric generator cold and hot parts are measured with six thermocouples, three for each part, using the NI 9213 thermocouples module of the cRIO integrated system. The positioning of the thermocouples to measure the temperature of the thermoelectric generator can be seen in Fig.3. Three thermocouples were used to have a relatively complete temperature picture.

The experimental set-up to study the behavior of the commercial Bi_2Te_3 thermoelectric generator is presented in Fig.4. The control of the programmable DC power supply, the measurements and the control of the water flow are realized using the software made in the graphical programming language LabVIEW.

4. RESULTS

The I-V characteristics for the thermoelectric generator were measured at different temperature differences between the hot and cold parts. The temperature difference was obtained through power variation on the second thermoelectric device with a DC programmable power supply.

The I-V and P-V characteristics of the thermoelectric generator at different temperature differences are presented in Fig.5a and in Fig.5b.

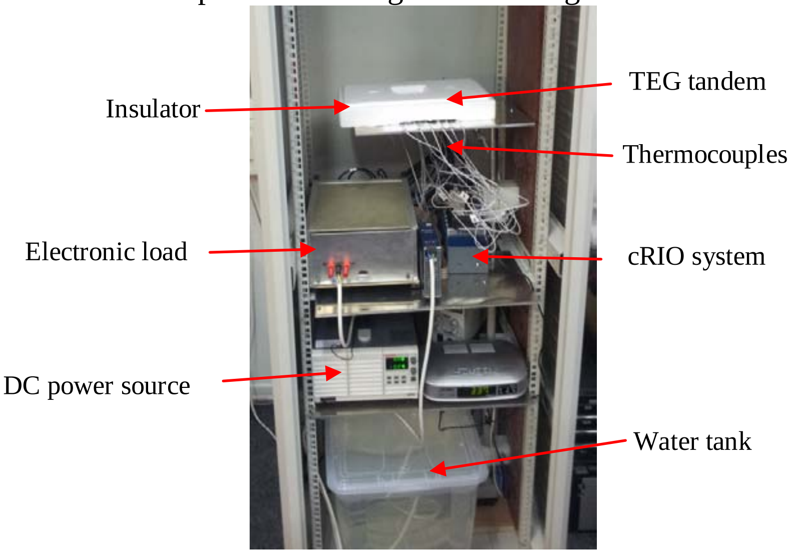
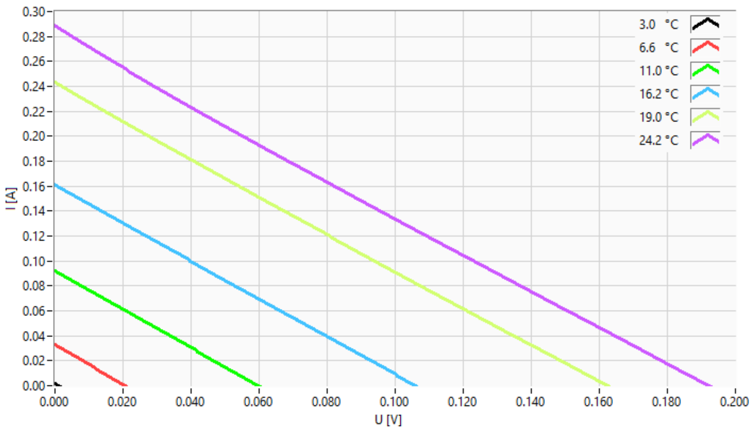


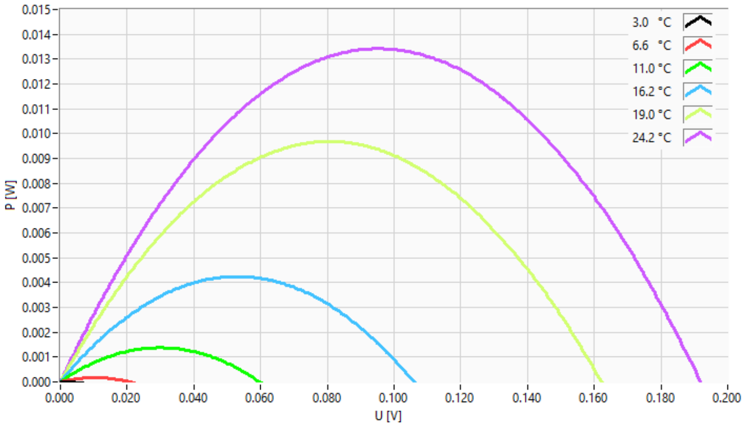
FIG. 4. The experimental set-up to characterize the thermoelectric generator

By analyzing the maximum power generated by the thermoelectric generator in function of the temperature difference, a parabolic dependence can be observed. This dependence is given by the equation (6) obtained by polynomial fitting, Fig.6:

$$P_{\max} = 0.039 \cdot 10^{-3} \cdot \Delta T^2 - 0.032 \cdot 10^{-3} \cdot \Delta T - 0.1 \cdot 10^{-3} \qquad (6)$$



a)



b)

FIG. 5. (a) The I-V characteristic of the Bi_2Te_3 thermoelectric generator in function of the temperature
(b) The P-V characteristic of the Bi_2Te_3 thermoelectric generator in function of the temperature

The equation (3) becomes (7) at the open circuit voltage point where the current is equal to zero:

$$\alpha = \frac{V_{oc}}{T_h - T_c} \tag{7}$$

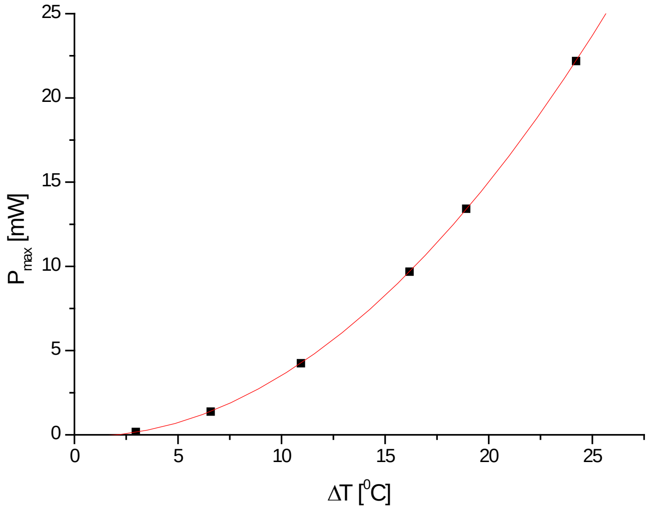


FIG. 6. The P_{max} vs ΔT for the Bi_2Te_3 thermoelectric generator

The Seebeck coefficient can be determined using equation (7), if the temperature of the thermoelectric generator's hot part is varied. The slope of the linear dependence between the open circuit voltage, V_{oc}, and the temperature difference between the hot and cold parts of the thermoelectric generator, is the Seebeck coefficient, see Fig.7. The slope is obtained by linear fitting and the value of the Seebeck coefficient is 10.75 mV/°C.

The internal resistance of the thermoelectric generator increases when the temperature difference increases, see Fig.8. The value of the internal resistance increases with 12% when the temperature difference increases with 21°C.

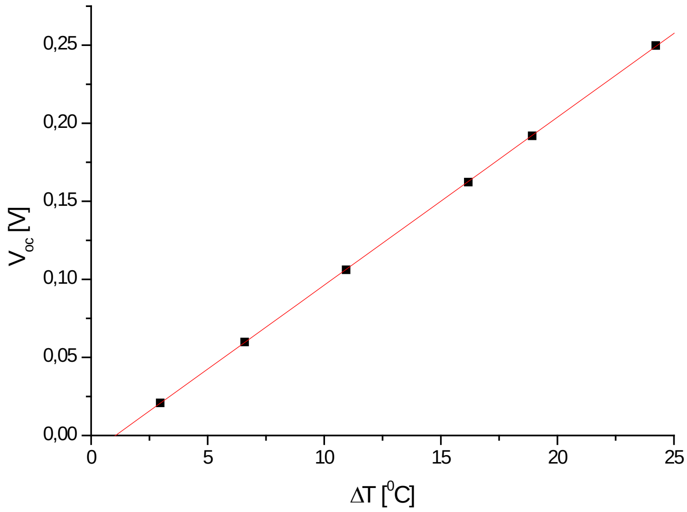


FIG. 7. The V_{oc} vs ΔT for the Bi_2Te_3 thermoelectric generator

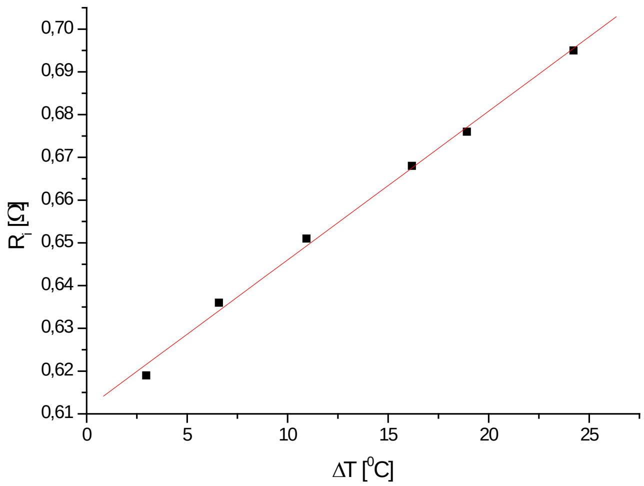


FIG. 8. The R_i vs ΔT for the Bi_2Te_3 thermoelectric generator

CONCLUSIONS

The thermoelectric generators produce renewable energy, but they still have a low efficiency. Using the new types of materials such as the graphene and nanomaterials the efficiency of the thermoelectric generators can be increased and then, the number of their application will also notably increase.

The commercial Bi_2Te_3 thermoelectric generator was analyzed in the paper. The I-V and P-V characteristics at different temperatures were measured and analyzed.

A polynomial model for the maxim power of the thermoelectric generator function of the temperature was identified.

The Seebeck coefficient was determined and the dependence of the thermoelectric generator internal electric resistance function of the temperature was studied.

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