

Performance Study of Thermoelectric Generator Using Waste Heat

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Abstract—There is a lot of waste heat from power consuming companies. This waste heat is added to the atmosphere, which is unusable and it adds to global warming. Most of the energy sources are consumed by energy sectors. These sectors are energy spending sectors all over the world. Consequently, they are answerable for the discharging of a huge quantity of heat to the atmosphere. This heat is called waste heat which is in the form of hot exhaust gases or other hot discharges. Since the high prices of sources and wastage of heat made us think that to recover its energy. It will benefit us from two perspectives in which the first one is decreasing the carbon amount in discharges and the second one is that this energy is cheap. Moreover, decreasing the ecological impact. Heat recovery via thermoelectric modules enables us to recover the waste contents with energy. Thermoelectric generator (TEG) is a semiconductor device. TEG module is made which produces electrical voltages whenever a thermal gradient is developed on its surfaces. The study of TEG performance is presented in this paper. Voltage, current and power produced are the performance characteristics of TEG. The increase and decrease of temperature difference on both the surfaces of TEG module will show the output results increasing and decreasing respectively [1].

Keywords— Bi₂Te₃ TEG, waste heat recovery, thermoelectric system, thermoelectric modules.

I. INTRODUCTION

Out of 100% energy used in productions, 33% of it is discharged out which is named as waste heat [2]. Presently the world is facing issues related to global warming, high prices of fossil fuels and its depletion. Therefore we must need to develop other methods to fully fill our needs of energy. So we are moving towards clean and green energy technologies and also developing more efficient ways for energy recovery of heat and heat transformation systems using the pumped out waste heat as a source.

In process industry low grade heat energy is pumped out. This heat is considered useless because of a low degree of temperature. For generation of electrical power by old generation systems which use rotating parts like turbines, it is very hard to get energy of this waste heat from waste heat of low temperature and low energy density. Some well known systems are available

for the conversion of heat of low temperature which are ORC (Organic Rankine Cycle). But we have some issues using this kind of system as they are costly and they have rotatory parts which will need maintenance periodically, which is not economical.

Conversion of heat of low temperature to energy of electrical form, we need to choose an economical method. We need a similar method like solar cells which is economical and one-time costed. Capital cost is less. Maintenance on a periodic basis should be not included for which we need to ignore the rotatory parts. So we need a system which operates without rotatory parts and is easy to handle. We have a method used for heat recovery called heat pipe. Which is the best method of all having more applications in this field [4]. There is another method called direct energy conversion from thermal form to electrical form by using a device or module called thermoelectric generator. This TEG system is having good performance of conversion of thermal energy to electrical. The TEG is kept between two surfaces in which one is heat source and other is heat sink or heat exchanger based on the Seebeck effect [7]. TEG is the best device for using on low temperature of pumped out heat. As this device is what we needed that doesn't have any movable part. So its maintenance cost is negligible. And its size is very small [8].

In the current market, the efficiency of TEG is low which is lower than five percent, but still some people claimed that they are obtaining more than 20% efficiency. NASA lab of jets also discovered more than 20% efficiency of TEGs [2].

Researches are in progress just for increasing the efficiency of TEGs, but still there is wastage of heat energy in three different forms. In which along with gases, solid and liquids are counted [11]. In France 75% of energy is used in process plants out of which 31% of heat is further wasted [12]. USA discharges 20-50% of the energy as heat [13]. Turkey cement plants lose 51% of the total heat energy used [14]. We have many other countries that pump out the waste heat to the outside world. Which is dangerous for the life on the earth for all animals and every kind of organisms.

It is considered that in the near future power will be produced by TEG system which will utilize the waste heat efficiently.

II. LITERATURE REVIEW

A. Waste Heat

Waste heat refers to that energy which is considered useless. It is generated in process industries. Currently 20-50% of fuel energy is added to the environment by convection, conduction and radiation. Waste heat has three categories. Temperature above 600°C is considered high, below 230°C is considered low and in between is medium category. There are several advantages of waste heat. It is free source of energy. It reduces energy consumption in furnaces and boilers. It improves efficiency of plant more than 50%. It can be converted to other form of energy.

B. Thermoelectricity:

The phenomenon in which temperature difference generates electrical power and vice versa. The three effects, Seebeck effect, Peltiers and Thomson effect, plays very important role in thermoelectricity.

C. Thermoelectric devices

Thermoelectric (TE) devices are the centre of attention because of their role that they have ability to directly convert heat energy to electrical energy. It is prepared of semiconductors. Usually the shape of this device is a rectangular boxes in parallel as shown in figure 1. These units are combined in parallel or in series according to the need.

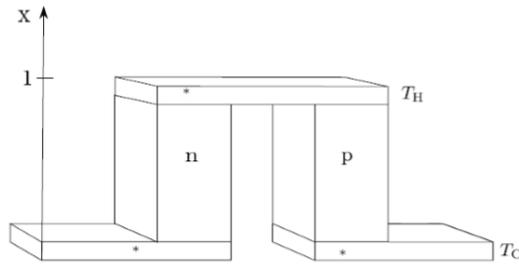


Figure 1.

D. Thermoelectric devices and Thermoelectric effect:

Thermo stand for heat energy and Electric for electrical power. So it means conversion of heat energy to electrical directly. We will discuss three effects here. Thomas Johan Seebeck for the first time in 1821 observed that if a circuit is made of two different metals. A measuring instrument needle is deflected when heat was applied to the metals. This effect was named as Seebeck effect and eq 1 is given below. The second one was named as Peltier effect which is opposite of Seebeck effect was observed by him. The current passed through two metal produced heat and equation 2 is given below. Thomson and joule effects are not discussed in detail as they are not used in this research.

$$I = \sigma E - \sigma \alpha \nabla T \left(\frac{A}{m^2} \right) \quad (1)$$

$$q = \pi I - k \nabla T \left(\frac{W}{m^2} \right) \quad (2)$$

Where, E is symbol of electric field, T is symbol for temp, α is symbol for Seebeck coefficient, π is symbol for Peltier Coefficient, and σ is symbol for electrical conductivity. Symbol k is for thermal conductivity. From eq 1 and 2 we can say that heat and electrical energy in transformable into one another.

The direct relation of Seebeck effect to the Seebeck coefficient is defined by:

$$\alpha = - \frac{\Delta V}{\Delta T} = - \frac{V_{hot} - V_{cold}}{T_{hot} - T_{cold}}, \alpha [V/K] \quad (3)$$

The relation of Peltier effect to the peltier coefficient is defined by:

$$Q_p = \pi I = \alpha T_j I \text{ or } \pi(T) = \frac{Q}{I} \quad (4)$$

Both these relations in eq 3 and eq 4 were combined and experimentally by Lord Kelvin. The relation of α and π is given by:

$$\alpha(T) = \frac{\pi^*(T)}{T} \text{ Kelvin relation} \quad (5)$$

Showing that only Seebeck coefficient will do all to describe all the TE properties of TE material.

Semiconductors of N-type and P type have dissimilar properties. That's why we get opposite signs of Seebeck coefficients. TE modules are generally prepared from two semiconductor materials which are connected in series electrically. And in parallel thermally. See Figure 2.

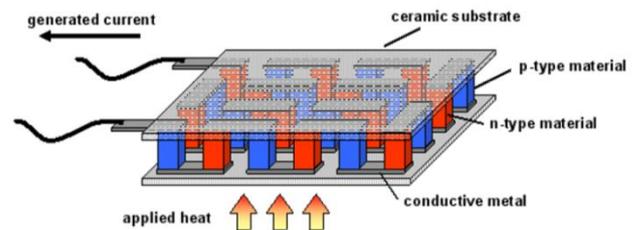


Figure 2.

The eq 5 is efficiency for TE module

$$\eta_{max} = \frac{T_H - T_L}{T_H} \sqrt{\frac{1 + \frac{Z(T_H + T_L)}{2} - 1}{1 + \frac{Z(T_H + T_L)}{2} - \frac{T_L}{T_H}}} \quad (5)$$

Eq 6 is just like the efficiency of ideal Carnot engine and is multiplied by Z factor. Z is called figure of merit, given by:

$$Z = \frac{\alpha^2 \sigma}{k} \quad (6)$$

σ is symbol used for electrical conductivity. Symbol k represents thermal conductivity.

V-I characteristics of TE modules are shown in figure 3. The power and voltage graph is here for commercial thermo electric module when 20watts of heat flux is applied to the sides.

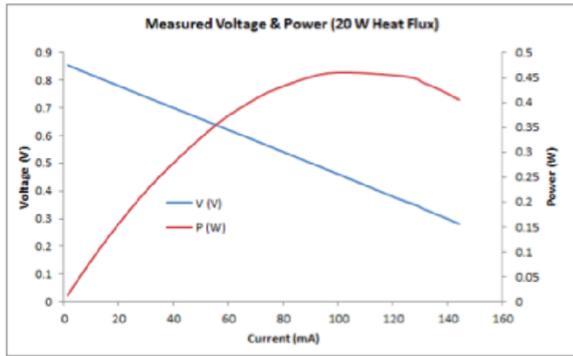


Figure 3.

The highest point for the max power is expressed by:

$$I_{Pmax} \approx \frac{\alpha (T_H - T_L)}{2R_e} \quad (7)$$

Where R_e is the module electrical resistance.

E. Advantages of thermoelectric generators

The advantages of TEGs are large in number but some are:

- Most reliable device which exceeds over 100,000hours of life.
- No moving part so don't produce any noise.
- Compact size and simplest construction design.
- Lowest weight and smallest in size.
- Work with high degree of temperature.
- Best option for distant places where there is no energy.
- Eco-friendly system.
- No problem of position placements.

F. Applications of TEGs:

For combustion engines it is best option to combine TEGs with them and recover the hot gases heat energy. With solar energy the solar panels get heated so that energy can be recovered by using TEGs with them and more energy can be utilized from the solar. The solar panels efficiency can be raised up by adding its power. Very light generating system enables us to use it everywhere in the world. Even on spaceships we can provide power to them by the heat recovery method using TEGs.

III. WORKING PRINCIPLE OF TEG

Working principle of TEG is based on the Seebeck effect which is described in detail. When two unlike materials are joined and they make two junctions and they both these metals are provided with different temperatures. On the output we will get generated voltage of micro volts per degree kelvin. The material we use for thermoelectric generation is called thermoelectric material. seebeck coefficient and properties like electrical and thermal were kept in consideration for selection of this material which is very important.

The generated power of TEG is dependent upon the applied temp difference to its opposite surfaces. The conduction of the heat from one surface to the other takes place and in this way the difference of temp is reduced. Hence a heat sink will be required on the second surface to maintain proper temperature difference between plate surfaces. our aim is to study the performance of TEG for vaious temp gradients.

IV. METHODOLOGY

We have numerous number of materials for preparing TEG modules. But we have choosen Bismuth Telluride because of better power ratings and easy availability in market. Therefore we preferred studying Bi_2Te_3 Module. Maintaining constant difference of temperature is very important so for that purpose a heat sink is designed for the faces of TEG. As heat sink we preferred to use Aluminum for its property of high thermal conductivity. The amount of heat required to be pumped and water flow rate are the two parameters needed to be considered. In heat sink a flow rate was kept constant. The TEG specs as given below.

- 230°C is limit of operating temp.
- OC voltage is 12.1v. (OC stands for open circuit)
- Dimensions are (40mm x 40mm x 3.4mm).
- Properties of Bi_2Te_3 are:
 - Condcuts heat of 2W/m-K.
 - Its density is 7790 Kg/m³
 - Specific heat transfer is 250 J/Kg-K

Cover of 0.8mm made of porcelain is used on both sides of TEG. Thermal conductivity of porcelain is 30W/m-K. And 3300Kg/m³ is the density of porcelain.

V. EXPERIMENTAL SETUP

Figure 4 and 5 shows a custom made test bench is being used in this test. This apparatus is composed of electric heater with adjustment knobs and TEG made of thermocouple modules. Heat exchanger or sinker is added on the second side of the modules. This sink helps in creating high temperature gradient which further helps in maximum power generation. A voltmeter and ammeter was used to for measuring voltage and current from modules connections.

A heater or heating plate in this setup is used to supply heat to bottom side of the module. From ammeter and voltmeter we noted the readings. The readings range was started from 35°C and we raised with steps of 10°C upwards until 145°C was reached.

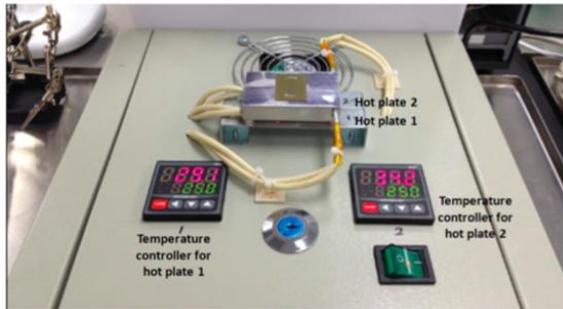


Figure 4.

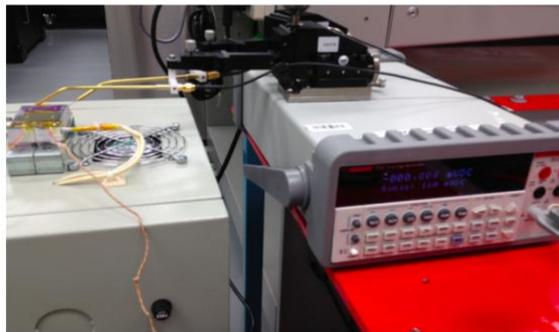


Figure 5.

TABLE I. SHOW THE TEMP VS VOLTAGE, CURRENT, AND POWER

Temp (°C)	Voltage (mV)	Current (mA)	Power (mW)
35	21.80	1.000	0.02180
45	443.0	1.900	0.84170
50	464.5	3.651	1.73305
60	497.0	9.201	4.61420
70	539.0	18.95	10.3985
80	607.5	30.45	18.7065
90	693.5	44.01	30.9020
100	795.0	64.40	51.8552
110	975.0	86.60	85.6897
120	1225	109.1	134.940
130	1513	144.8	222.775
140	1879	187.0	355.192
150	2184	218.5	478.388
155	2287	231.0	528.297

VI. RESULTS

The Reading were pen down from 35°C with 10 degrees steps increment upto 150°C. The temperature vs voltage graph is show in figure 6. Figure 7 shows the temperature vs current graph and figure 8 show the temperature vs power graph.

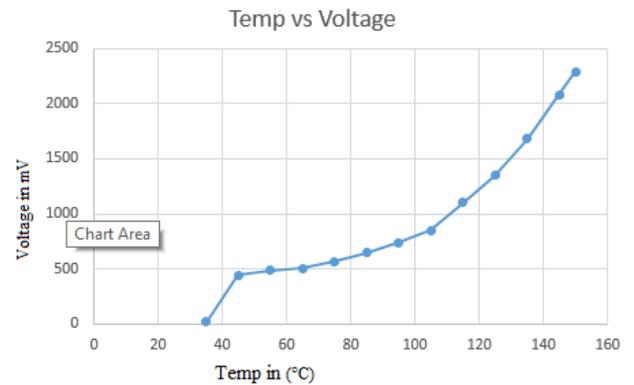


Figure 6.

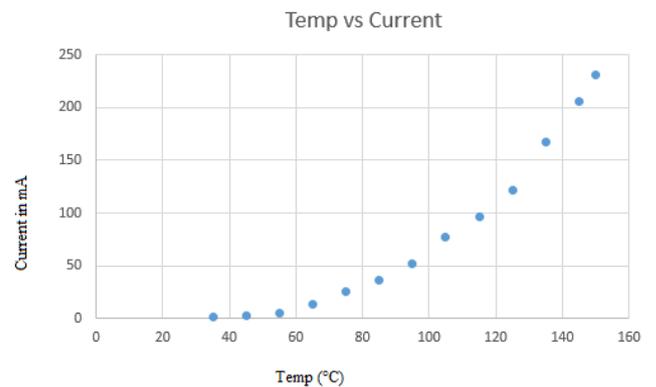


Figure 7.

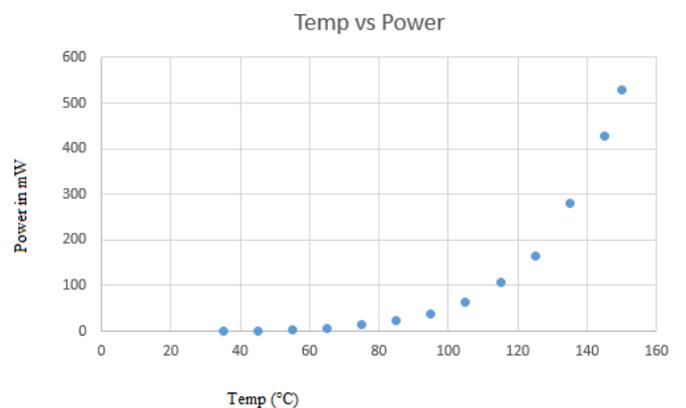


Figure 8.

CONCLUSION

The full pledge details about the study of Power generation by using thermoelectric generators were presented in this paper. the applications of TEG are also described as its is very efficient system from the heat recovery point. this study is very important to understand the use of Bismuth Telluride as thermoelectric generator when there is free of cost available waste heat like heat of engines, furnaces, or other processes industries. In this paper we can conclude that the electrical power produced is directly proportional to the heated surface

provided. Maximum output power obtained was 528.297 mW. Further experiments are soon be conducted in order to improve the efficiency and performance of systems using heat recovery process.

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