TITLE: An Overview of the Applications and Performance Characteristics of the Thermoelectric Devices

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ABSTRACT

Thermoelectric power generation has proven to be the best technology for small scale power generation for portable power systems. Looking at the advantages of the thermoelectric power generation there is a need to review applications and fundamentals of the power generation through thermoelectric set up. Present review emphasizes mainly on applications and parameters affecting performance of the thermoelectric device, which includes materials of thermoelectric, geometry of the thermo electric material and heat source, temperatures obtained from heat source, efficiency of the heat source, efficiency of the thermoelectric device on low temperature and high temperatures, connectivity issues etc. Findings from all the points mentioned above are sorted after every point and collective conclusions are drawn at last. Future modifications/recommendations are suggested in the existing power generatingsystems.

Keywords*: Thermoelectric device, thermal performance, electric performance, geometries, materialetc.*

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1. Introduction

Looking at the trend towards small scale power generation, which is used for portable systems reviews and precise suggestions are very important. Beauty of non moving parts in the thermoelectric power generation increases importance of the system at small scale power generation [1] e.g. internal combustion cant be manufactured at small scale, because of its high frictional and heat losses [1], but system which is using thermoelectric devices can be easily used to produce power at small scale because of non moving parts [2 -9].

Nomenclature:

Notation	**Description**
σ	Electrical conductivity
TH	Hot side temperature
TC	Cold side temperature
ZT	Figure of merit
S_p	See beck coefficient of p junction
S_n	See beck coefficient of n junction
S	See beck coefficient
P	Electrical resistivity
K	Thermal conductivity
Q_{max}	Maximum heat input
I_{max}	Maximum current
V_{max}	Maximum voltage

Bi	Bismuth
Sb	Antimony
Te	Tellurium
N	Carrier concentration
M	Effective mass of carrier
Pb	Lead
Si	Silicon
Ge	Germanium

Fundamental principles by which electricity is produced using thermoelectric devices are Seebeck effect and Peltiereffect which are explained below.

1.1 Seebeck Effect

The basic principle on which the thermoelectric devices work is a Seebeck principle. Generation of electrical power output when exposed to the temperature gradient is due to the Seebeck effect [2].

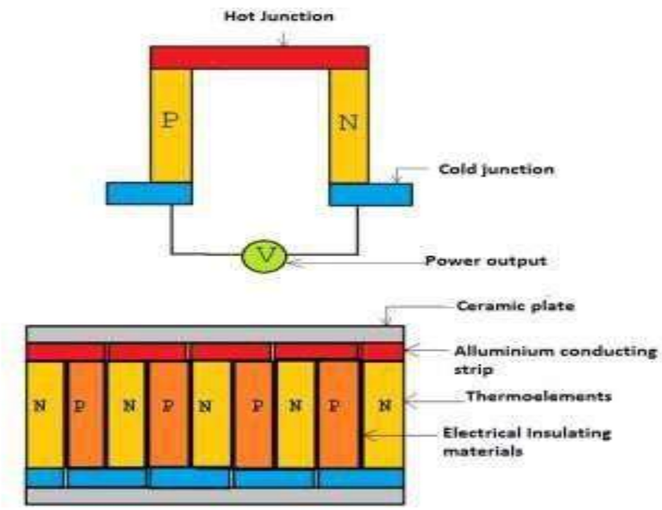

Fig.1. Seebeck effect [3]

Fig. 1 explains the working principle of Seebeck effect used in thermoelectric power generation. Seebeck effect mainly works on creation of the temperature gradient between two junctions of the thermoelectric power generator. Temperature gradient is created between two junctions (i.e. one end is hot and other one is the cold end of the generator) across the thermoelectric power generator. Generated voltage can be used for running various applications like cellular phones, small capacity fans, battery charging, microaerial vehicles, unmanned aerial vehicles, remote sensors, divert and attitude control systems etc. Power factor of thermoelectric device is formulated as [1-5]:

$$ctr = \sigma 2$$

Equation (1) shows the relation between power factor, Seebeck coefficient (S) and electrical conductivity (ς) [5], Materials which have higher electrical conductivity helps in generation of higher power factor which in turn helps to produce high power output [3]. Thermoelectric power generator is a power generating device whose efficiency is limited by Carnot efficiency, this is mentioned in eq. (2) [3]

$$\eta_{max} = ((TH - TC)\sqrt{1+ZT}) \frac{1}{((TH)(\sqrt{1+ZT})+(\frac{TH}{TC})} \quad (2)$$

Where, TH is hot side temperature and TC is cold side temperature. ZT here is figure of merit which is shown in eq. (3) [3],

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$$ZT = \frac{[(Sp-Sn)^2(T)]}{[(\rho nKn)^{1/2}+(\rho pKp)^{1/2}]^2} \quad (3)$$

Where, ρ is electrical resistivity, T is average temperature between hot and cold sides. Equation 3 is useful when parameters related to p and n type materials are known. Subscripts n and p indicates properties related to p and n type of semiconducting materials [1].
Thermoelectric power generating device efficiency can be given as [3],

$$\eta = \frac{\text{Energy provided to load}}{\text{Heat absorbed at hot junction}} \quad (3)$$

Ability of a given material to efficiently produce thermoelectric power is related to its dimensionless figure of merit i.e. ZT, [3]

$$ZT = \frac{\sigma s^2 T}{K} \quad (4)$$

Where, σ is electrical conductivity, K is thermal conductivity, S is Seebeck coefficient and T is average temperature.

1.2Peltier Effect

Peltier effect describes a principle in which heat is given out or absorbed by thermoelectric device, when an electric current passes across a junction between two materials [2- 9].

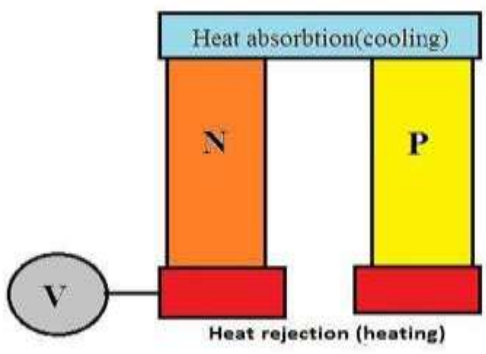

Fig.2. Peltier effect [3]

Figure 2 shows basic principle of Peltier effect for the cooling applications (e.g. Refrigeration) by using thermoelectric device. Constant voltage is supplied to the thermoelectric device as shown in fig. 2, which helps to generate a cooling effect by absorption of heat from the surface which is to be cooled.

2. LITERATURE REVIEW ON APPLICATIONS OF THE THERMOELECTRIC POWER GENERATOR

There are many research on applications of thermoelectric module, few of them are explained below:

1.A Russian scientist developed generator to operate radio receiver by using thermoelectric module, in which he used standard oil lamp as a heat source [6]. He used 3000 thermocouples in this design, but this was not optimized design because of low power output[6]and so he produced another generator by using kerosene burner[6].

2. Figure 3 shows miniature thermoelectric generator that was discovered in 1988 by [7] and was used to run small scale applications like charging or running a watch battery, domestic water heating component,etc.

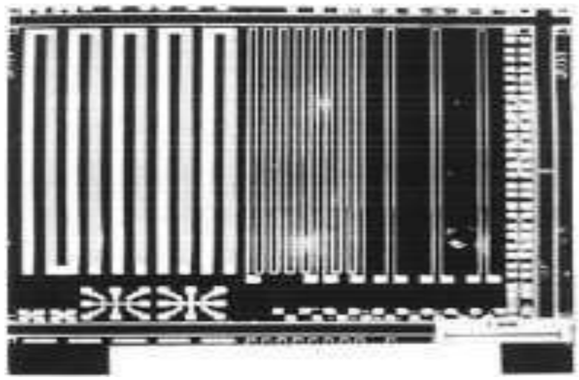

Fig.3. Miniature thermoelectric power generator photograph [2]

3. GEOMETRIES OF THE THERMOELECTRIC AND DEVICES

Thermoelectric devices are mainly available in two types which are as follows.

1. TEC: - Thermoelectric cooler (which is used for refrigeration applications and it uses Peltier effect)
2. TEG:-Thermoelectric generator (which is used for generating electricity by using Seebeck effect)

Thermoelectric devices are available in shape of square plate having dimensions approximate about 50 mm X 50 mm X 3 mm [3]. Similarly, maximum current, voltage, heat energy in watts, and temperature difference are mentioned in the table1.

Table.1 Performance parameters of TEC1-12706 [3]

Hot side Temperature (^{o}C)	25^{o}C	50^{o}C
Q_{max} (Watt)	50	57
Delta T_{max} (^{o}C)	66	75
I_{max} (Amps)	6.4	6.4
V_{max} (Volts)	14.4	16.4
Module Resistance (Ohms)	1.98	2.30

4. MATERIALS OF THE THERMOELECTRIC DEVICES

That will lead to the reduction in fossil fuel consumption & CO_2 emissions [10]. The basic problem in creating efficient thermoelectric materials is that, they must be very good at conducting electricity but not heat [16]. In that, one end of an apparatus can get hot while other remains comparatively cold [16-19]. The main focus of research on thermoelectric materials is to improve electrical conductivity without an increase in the thermal conductivity [16]. Thermoelectric materials are associated with the issues like life, reliability of the thermoelectric device, toxicity and very less efficiency (about 5-8%)[52-54].

Thermoelectric materials such as alloys of Bi_2Te_3, PbTe, and BiSb were developed 50-60 years ago [17]. They are generally limited to use in a temperature range between 200 K to 1300 K [16]. The best thermoelectric materials that are currently in use in devices have a value of ZT is equal to 1 [13]. Besides that we have to look at power output. For most thermoelectric material power factor 40 is good whereas many researchers have used a power factor in the range of 20 or 30. The new material has a power factor of 106 at room temperature & researchers were able to demonstrate an output power density of 22 watts per square centimeter, which was 5 to 6 watts higher compared to typically produced in thermoelectricdevices.

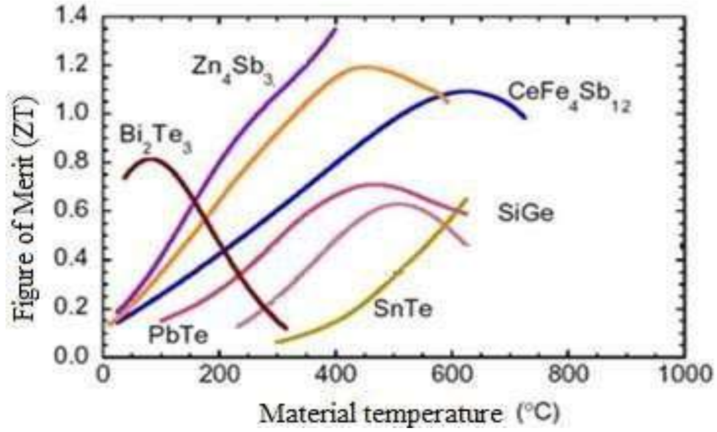

Fig.4. Relation between ZT and Temperature [2]

Figure shows the behavior of different thermoelectric materials with respect to temperature and ZT. As Temperature increases ZT also increases, but it is observed that after particular rise in temperature ZT starts to decrease. Alternative material classes are provided like nano- structured, semi conductors, and superlattice materials [10]. The new classes can allow waste heat recovery with better efficiency [10].So it can be concluded that thermoelectric materials should have a low thermal conductivity and a high electrical conductivity.

Findings: Thus materials suitable for high temperature application are alloys of Silicon and Germanium which can operate upto temperature of 1300K.Materials suitable for medium temperature range of 500K to 850K

5. INFLUENCE OF THEORETICAL PARAMETERS ON PERFORMANCE OF THE THERMOELECTRIC DEVICE

The efficiency of thermoelectric generator is the ratio of energy provided to load as electrical power to the rate of thermal energy consumption.Thermoelectricdevice is made up of p- type and n-type semiconductor. They both are considered as thermocouple. The electrical conductivity is inversely proportional to the resistivity as given in equation (7) by [6],

$$\sigma=1/\rho \qquad (7)$$

Where T_h and T_c are temperatures on the hot and cold sides of element respectively and T is average temperature of T_h and T_c . Hot side temperature is 250^0C and cold side is 50^0C, that increases ZT from 1 to 3 corresponds to increase in efficiency from 11% to 19% for simplest design of devices[21].

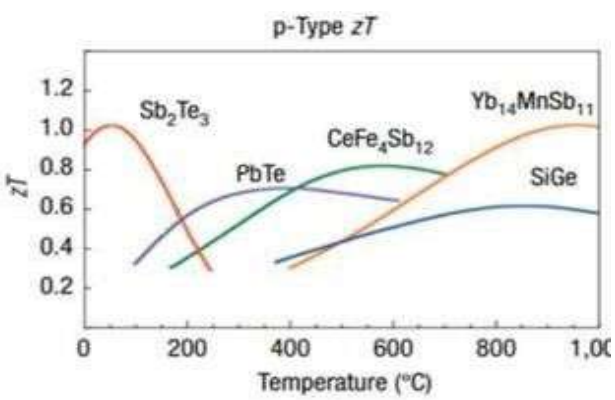

Figure 5. (a) and (b) Shows the relationship between ZT and temperature for n-type and p-type material.

6. CONCLUSIONS

Power consumptions and waste emissions can be reduced to a greater extent by the use of thermoelectric devices. Industrial waste heat recovery as well as domestic heat recovery applications can help a lot for reducing wastage of heat. Thermoelectric material should have low thermal conductivity as well as high electrical conductivity.Temperatures, figure of merit, material, and connectivity issues were significant parameters for maintaining required performance of the thermoelectric device. Simplicity, low cost and practically no need of device maintenance were advantages of the thermoelectricdevice.

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