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Optimization of Segmented Thermoelectric Generator and Calculation of Performance

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ABSTRACT

Nowadays, the use of thermoelectric coolers and generators has greatly increased. Applications of this phenomenon include electronic cooling, portable refrigerator, air conditioning, high-precision temperature measurement and space applications. The phenomenon of thermoelectricity has outstanding features compared to other energy conversion methods, such as exclusion of moving parts, high reliability and long life span.The requirements for high temperature heat source and low efficiency are the remarkable challenges of this method. Today, the first challenge has been overcome, thanks to abundant wasted heat sources, *while* increasing the efficiency of thermoelectric devices are under extensive studies. Segmentation is a popular way for the increment of thermoelectric efficiency that is focused on in this paper.

KEYWORDS

Thermoelectric Optimization, Maximum Efficiency, Segmented Thermoelectric

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1- INTRODUCTION

Nowadays, the applications of thermoelectric (TE) coolers and generators have greatly increased. These phenomena are applied in electronic cooling, portable refrigerators, air conditioning, and high-precision temperature measurement and space applications. The TE phenomena have outstanding features compared to other energy conversion methods. Exclusion of moving parts, high reliability, and long life span are the bold advantages of TE [1]. The hot heat source and low conversion efficiency are the remarkable challenges of this phenomenon. The first challenge is no longer a problem, thanks to abundant waste heat sources, and while many studies have carried out to increase the efficiency of TE, many more are still needed. The effort to enhance TE efficiency is classified into three categories, i.e. invention and development of highly efficient materials, segmentation and cascading.

In this paper, a major study has been done on the latest thermoelectric materials known up to 2010, the best of which have been used for the design of a thermoelectric generator. Due to the figure of merit dependent on temperature, attempts have been made to choose the materials with a high figure of merit in a specific temperature range. Figs. 1 and 2 show the variation of figure of merit with temperature for n and p-type legs, respectively.

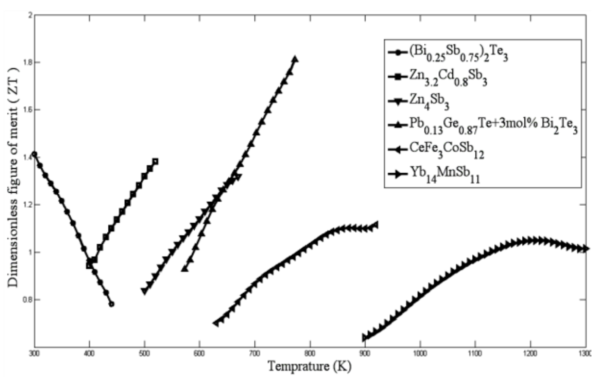

Figure 1: variation of figure of merit with temperature for p-type materials

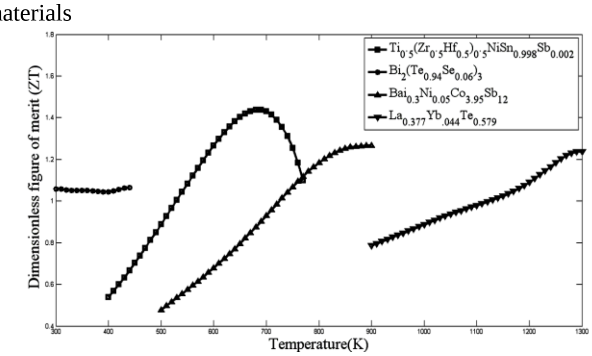

Figure 2: variation of figure of merit with temperature for n-type materials

Two arrangements have been optimized for each of n and p type legs. Next, by using these materials, a segmented thermoelectric generator has been proposed and analyzed. The materials used in the mentioned arrangement as well as temperature ranges have been shown in tables 1 and 2.

TABLE**1**

PROPOSED ARRANGEMENT FOR P-TYPE LEG

Temp. range	material
330-440	$(Bi_{0.25}Sb_{0.75})_2Te_3$
440-520	$Zn_{3.2}Cd_{0.8}Sb_3$
520-670	Zn_4Sb_3
670-770	$Pb_{0.13}Ge_{0.87}Te$+3mol% Bi_2Te_3
770-920	$CeFe_3CoSb_{12}$
920-1300	Yb_{14} $MnSb_{11}$

TABLE **2**

PROPOSED ARRANGEMENT FOR N-TYPE LEG

Temp. range	material
440-300	$Bi_2(Te_{0.94}Se_{0.06})_3$
770-440	$Ti_{0.5}(Zr_{0.5}$ $Hf_{0.5})_{0.5}$ $NiSn_{0.998}$ $Sb_{0.002}$
900-770	$Ba_{0.3}Ni_{0.05}Co_{3.95}$ Sb_{12}
1300-900	$La_{0.377}Yb_{0.044}$ $Te_{.579}$

Finally, the design and performance characteristics of the optimized generator at maximum efficiency including length of elements, electrical current, cross section area ratio and resistance ratio have been calculated. The overall length of each leg and the cross section of p-type legs are assumed at 10mm and 100mm^2, respectively.

The maximum efficiency for the generator in a temperature range of 300-1300 K is equal to 23.48% which shows a 5.3% increase in comparison to the Snyder [2] arrangement which is 18.1%.

Design and performance characteristics of the generator at maximum efficiency are shown in the table and compared with the previous generator presented by JPL (jet propulsion laboratory) [3].

TABLE 3

DESIGN AND PERFORMANCE CHARACTERISTICS OF THE PRESENTED GENERATOR VERSUS FLEURIAL'S ONE

Parameter	Fleurial'sgenerator	Present generator
Length(mm)	10	10
Cross section area of P-type leg(mm^2)	100	100
Hot source heat(W)	66.11	51.9301
Cold source heat(W)	58.08	39.7638
Output power(W)	8.81	11.9556
Maximum efficiency (%)	13.33	23.4469
Cross section area of n-type leg(mm^2)	88.31	96.51
Lengths of P-leg materials(mm)	5.104 & 0.681 & 4.230	1.821 & 3.05 & 8.33 & 1.328 & 3.179 & 2.534
Lengths of N-leg materials(mm)	4.639 & 5.341	1.311 & 5.032 & 2.309 & 1.348
Current (A)	34.327	39.70
Resistance ratio	1.481	1.54

Enhancing thermoelectric efficiency opens the way to generate electrical power especially by using wasted heat as a hot source. Owing to great attempts and investigation to improve thermoelectric properties, especially based on nanotechnology, this direct energy conversion method is awaiting a bright future.

3- CONCLUSIONS

In this study, four segmented thermoelectric generators with the best thermoelectric materials, known up to 2010, were designed for operating between 300 and 1300K. The compatibility factor (a key factor in the design of segmented generators), was calculated for the materials used in each arrangement. The compatibility was satisfying in all of the proposed arrangements. The compatibility factor was calculated using both exact and approximate methods. The approximate method has a negligible difference in calculation of compatibility factor, but a considerable difference in calculation of efficiency. The Swanson et al. [4] method could cause a difference up to 20% in the calculation of some characteristics despite its sufficiently good results in efficiency.

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