Energy Conversion and Management 160 (2018) 176–181

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

An optimization study of structural size of parameterized thermoelectric generator module on performance

Jun Wang[a,*], Yilin Li[a], Chuang Zhao[b], Yixi Cai[a], Lei Zhu[b], Chaozhen Zhang[a], Jing Wang[a], Weidong Zhao[a], Peiguo Cao[a]

[a] *School of Automotive and Traffic Engineering, Jiangsu University, Zhenjiang 212013, China*
[b] *Kailong High Technology Co., Ltd, Wuxi 214000, China*

ARTICLE INFO

Keywords:
Thermoelectric generator
Screening optimization method
Parameterization
Performance
Optimization

ABSTRACT

A TEG module with 199 thermoelectric (TE) couples was simulated with constant and variable property parameters respectively. It is indicated that the simulative results with variable property parameters are closer to the experimental results. Meanwhile, it is found that the open circuit voltage and output power are proportional to the number of TE couples. The parameterized rectangle-TEG(R-TEG) and circle-TEG(C-TEG) modules with 2 TE couples were established respectively; it was found that the performances of TEG have not relevant to the shape of TE couple. When the hot side temperature is constant, the internal resistance, the open circuit voltage and the efficiency increased but the output power decreased with the decrease of cross sectional area; when the cross sectional area is constant, the open circuit voltage, output power and efficiency increased with the increase of the hot side temperature. The intersection of the respective output power and efficiency of R-TEG and C-TEG are regarded as an optimized value. The performances of the optimized R-TEG and the original TEG are compared, it can be seen that their output power and efficiency increase with the increase of hot side temperature. The maximum output power and efficiency of the optimized R-TEG can reach to 91.88 W and 4.5% respectively.

1. Introduction

In recent years, the issues of environmental pollution and energy shortage are increasingly prominent, it is necessary to find approaches to improving energy conversion efficiency and exploring alternative green energy [1–4]. Thermoelectric generator (TEG) has the advantages of compact structure, free maintenance, no moving parts, quiet operation, safety and high reliability [5–7], which has become one of the effective ways to recover low-grade energy. A lot of researches have been carried out about TEG module. Karri et al. [8] installed two TEG devices consisting of Bi_2Te_3 and quantum well (QW) respectively on a compressed natural gas generator. The thermoelectric properties of the two TEGs were compared. It is found that both TEG devices can achieve fuel saving and energy recovery. The conversion efficiency of the TEG device composed of the QW material was high. Orr et al. [9] proposed a new method for calculating the output parameters of TEG and verified it by experiments, the results showed that the theoretical value of the method was close to the experimental value and the deviation was small when the temperature difference was small. Omer et al. [10] described the application and development of $Bi_2Te_{2.4}Se_{0.6}$ alloy in TEG device, the conversion efficiency of TEG device could be improved by the process of melting furnace, high energy ball milling and hot pressing of alloy material. Zhang et al. [11] designed a TEG with high temperature resistant nanomaterials which was installed in a diesel exhaust system and its maximum conversion efficiency reached to 2.1%. The more electrical energy can be obtained when the nanomaterials was used, at the same time, the TEG device is not easy to damage at high temperature. Mal et al. [12] designed a TEG which was heated by a stove to generate power and it can be stored in a lithium battery to power supply for the phone and LED lights. Børset et al. [13] implemented a 0.25 m^2 TEG in the casting area of a silicon plant and the maximum power could reach to 160 $W\,m^{-2}$. The TEG could recover low-grade heat in life and produce electricity. Aranguren et al. [2] designed a flexible polymer TEG and found its power was lower than the bismuth-telluride TEG.

The output performance of the TEG module also depends on its size and construction [14]. Erturun et al. [6,15] analyzed the effect of different structural parameters such as geometry, size and spacing of TE couples on the thermal stress and thermoelectric output of TEG when the TEG device was operated at 20–120 °C, the width and height of TE couple are separate variable in the paper, however, research on structure optimization of a fixed volume TE couple would be meaningful.

* Corresponding author.
E-mail address: qcwjun@ujs.edu.cn (J. Wang).

https://doi.org/10.1016/j.enconman.2018.01.043
Received 23 October 2017; Received in revised form 17 January 2018; Accepted 18 January 2018

Ming et al. [16] simulated the arrangement and the body size of TE couples on a fixed substrate, proposed a compact TEG module, which changed the horizontal arrangement into oblique arrangement, and provided the theoretical basis for arranging the TEG modules in a narrow area. Huang et al. [17] presented the novel designs of a concentric cylindrical thermoelectric generator (CCTEG) and an annular thermoelectric module (ATEM) and compared the performance of ATEM and conventional square-shaped thermoelectric module (STEM); it was found that the open circuit voltage of ATEM is about 17% more than that of STEM. Montecucco et al. [18] studied the impact of the number and size of TE couples on output power when the TEG module is contacted to the heat source directly. But the damage caused by higher temperature difference was not taken into account. Barry et al. [19] believed that the maximum output power and conversion efficiency of the TEG module can be obtained by optimizing the length and cross section area of the P- and N-type semiconductors. Jia et al. [20] proposed a novel TEG with linear-shaped structure and studied the impact of different length ratio on output performance of TEG generator. Tian et al. [21] studied the segmented TEG module and established numerical model by using the low temperature TEG material Bi_2Te_3 and the medium temperature material respectively.

Based on the experiment of Hsu [22], a model of the TEG module with 199 thermoelectric (TE) couples is established with constant and variable property parameters respectively. We study the relationship between open circuit voltage, output power and the number of TE couples; it is found that the open circuit voltage and output power are proportional to the number of TE couples, so a TEG module with 2 TE couples was adopted to simulate. The parameterized rectangle cross section TEG(R-TEG) module and circle cross section TEG(C-TEG) module were established to study the variation of internal resistance, open circuit voltage, output power and efficiency with temperature difference and cross section size, the optimized values of R-TEG and C-TEG were found respectively. Finally, the optimized R-TEG and C-TEG module with 2 TE couples were enlarged to R-TEG and C-TEG module with 199 TE couples. When the cold side temperature of TEG module was fixed at 22 °C, we study the relationship between the open circuit voltage, output power of the original TEG, R-TEG and C-TEG and the hot side temperature of TEG module.

2. Basic theory of TEG

The geometric configuration of TEG module composed of one TE couple which is loaded an external load is shown in Fig. 1. The TEG module mainly includes P- and N-type semiconductor, electrical conductor (copper plate) and ceramic plates, the electrical conductor is connected with P- and N-type semiconductors and fixed on the ceramic plates.

When there exists a temperature difference between the hot and cold side, the output power of the TEG module is [23]:

$$P = I^2 \cdot R = \frac{(T_h - T_c)^2 \cdot (\alpha_P - \alpha_N)^2 \cdot R_L}{(R_L + R_{in})^2} = \frac{\Delta T^2 \cdot \alpha_m^2 \cdot R_L}{(R_L + R_{in})^2} \tag{1}$$

in which T_h and T_c represent the hot and cold side temperature of the TEG module respectively; α_P and α_N are the Seebeck coefficient of P- and N-type semiconductor respectively; $\triangle T$ is the temperature difference between the hot side and cold side of the TEG module; α_m is the relative Seebeck coefficient of P- and N-type semiconductor; R_{in} and R_L are the internal resistance and the external resistance.

When R_L is equal to R_{in}, the output power reaches its maximum value:

$$P_{max} = \frac{\Delta T^2 \cdot \alpha_m^2}{4R_{in}} \tag{2}$$

The efficiency is defined as [24]:

$$\eta = \frac{P}{Q_h} = \frac{P}{\alpha_m T_h I + K(T_h - T_c) - 0.5 I^2 R_{in}} \tag{3}$$

In which Q_h is the heat absorbed from the hot side of the TEG module; I is the closed loop current; $K = \frac{A_N}{L_N}\lambda_N + \frac{A_P}{L_P}\lambda_P$, it is the thermal conductance of the TE couple [25], λ_N and λ_P are the thermal conductivity of the N- and P-type semiconductors respectively; A and L are the cross sectional area and length of P- and N-type semiconductors respectively.

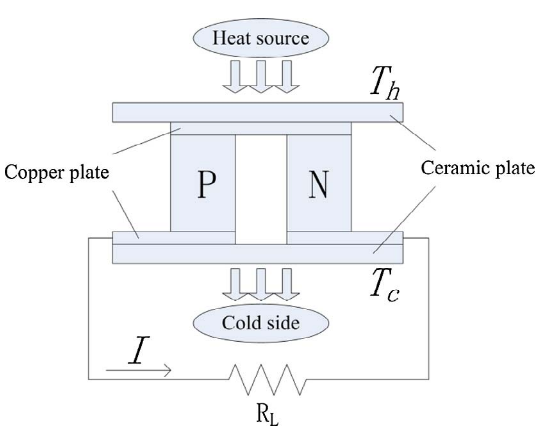

Fig. 1. Schematic diagram of TEG module.

3. Validation of the model and establishment of the parameterized model

3.1. Validation of the model

In this work, a TEG module with 199 TE couples which is used as the prototype is shown in Fig. 2, the dimensions of semiconductor and electrical conductor are 2 mm × 2 mm × 0.64 mm and 4.5 mm × 2 mm × 0.5 mm.

The TEG module is simulated with constant and variable property parameters respectively [22,26], as shown in Table 1. The cold side temperature is set up to 200 °C and the hot side temperature are set from 210 °C to 230 °C in the Cheng-Ting Hsu's experiment, the experimental and simulative results are shown in Fig. 3, it can be found that the open circuit voltage increases linearly with the increase of temperature difference, and the simulative results with variable property parameters are closer to the experimental results. The greater the temperature difference is, the greater the deviation is, and its maximum value is about 6%. Therefore, in the next study our simulation is carried out with variable property parameters.

Based on variable property parameters, the open circuit voltage and output power with the numbers of TE couples are shown in Fig. 4, it is found that the open circuit voltage and output power are proportional to the numbers of TE couples. In the follow-up study, a TEG module with 2 TE couples is regarded as study object. When the study is ended, the TEG module with 2 TE couples will be restored to the original TEG module with 199 TE couples.

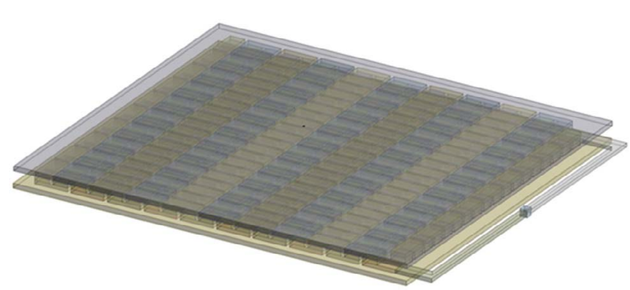

Fig. 2. TEG module with 199 TE couples.