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Energy Procedia 75 (2015) 590 – 596

Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

Comparison of segmented and traditional thermoelectric generator for waste heat recovery of diesel engine

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Abstract

This paper established a mathematic model of segmented thermoelectric generator (TEG) based on low-temperature thermoelectric material bismuth telluride and medium-temperature thermoelectric material skutterudite. The performance of segmented TEG and traditional TEG has been compared using this model under different conditions, such as heat source temperature, cold source temperature, heat transfer coefficient, and length and cross section area of thermocouple. The results show that the maximum output power and conversion efficiency of segmented TEG are higher significantly using exhaust of diesel engine (DE) as heat source and coolant as cold source. The results also show that the trends of maximum output power and conversion efficiency are contrary with increment of thermocouple length. The trends of maximum output power is linear with increment of cross section area, and the conversion efficiency is constant. Finally, the segmented TEG has a more potential to recover waste heat than tradition TEG. The performance of segmented TEG is decided by the ratio of materials, the optimum design of segmented TEG should base on the crossing point of *ZT* value for two materials.

Peer-review under responsibility of Applied Energy Innovation Institute

Keywords: Waste heat recovery in diesel engine; Segmented thermoelectric generator; Output power; Conversion efficiency

1. Introduction

Diesel engine (DE) is one of the main consumers of petroleum resources, which above 30% of fuel engine become waste heat [1]. If the waste heat can be recovered utilization, the thermal efficiency of DE can be improved. Many methods can be used in recovering waste heat of DE[2].Among them, the TEG can convert directly thermal energy into electric energy, which got more attention by many researchers [3,4].Although the TEG has many advantages, which makes the TEG has been used in recovering waste heat of DE, the low conversion efficiency limits the widely application. In fact, the conversion efficiency of TEG is mainly restricted by thermoelectric material. The *ZT* values of thermoelectric materials is change largely for wide temperature range[1]. The exhaust temperature of DE tested by our laboratory is about 523K when operating on low engine load and exceeds to 813K on high load. In general, the temperature of exhaust gas is above 600 K in DE [5,6]. The added *ZT* value of skutterudite and Bismuth

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Peer-review under responsibility of Applied Energy Innovation Institute
doi:10.1016/j.egypro.2015.07.461

telluride is higher that of each under the same range of temperature difference, when the exhaust of DE is as heat source. A segmented TEG has been suggested to recover waste heat of DE for improving the thermal efficiency in present paper. Many researched have been focus on the physical properties of segmented TEG [7-9]. However, it is nearly little used in waste heat recovery of DE.

2. Governing equations

Fig.1. shows that segmented TEG and traditional TEG. To simple the calculation progress, the performance of one thermocouple could be compared in present paper. The main purpose is to see that the performance of segmented TEG can be used in waste heat recovery of DE, which can be analyzed in the steady state of DE. Some assumptions are made as follows:(1)The heat conduction is flow along the direction of thermocouple leg. The heat conduction in the axial direction is omitted.(2) No contact thermal resistance and contact electric resistance.(3) Thomason and Fourier heat are ignored.(4) The temperature of heat and cold source are assumed as the surface temperature of two ends in thermocouple.

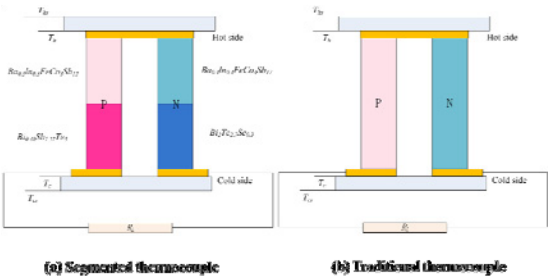

Fig.1. A structure of the theoretic model

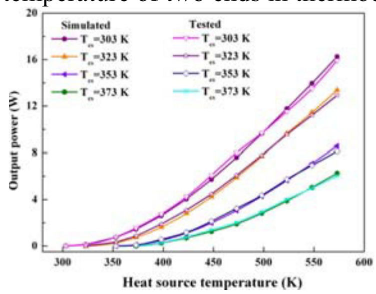

Fig.2. The comparison of simulated and tested results

The junction temperature will be set, which is validated by following equations. The heat flow equation of P-leg thermoelectric material in high temperature region and low temperature region is, respectively:

$$q_1 = \bar{\lambda}_1 \frac{T_h - T_{JP}}{l_1} \qquad q_2 = \bar{\lambda}_2 \frac{T_{JP} - T_c}{l_2} \tag{1}$$

Where q_1, $\bar{\lambda}_1 = \frac{\int_{T_{JP}}^{T_h} \lambda_1(T)\,dT}{T_h - T_{JP}}$ and l_1 stand for the heat flux, average thermal conductivity and length of thermocouple, respectively. T_h and T_c are assumed values in calculation process. Where $\lambda_1(T)$ stand for the function that the thermal conductivities vary with temperature of two materials.

According to the assumptions, the heat flux is equal in two materials of P-leg. So, the length rate of materials can be obtained from Eqs. (1):

$$\frac{l_1}{l_2} = \frac{\bar{\lambda}_1}{\bar{\lambda}_2} \frac{T_h - T_{JP}}{T_{JP} - T_c} \tag{2}$$

2.1. The output power and conversion efficiency

The internal resistances, average Seebeck coefficient of P-leg (same to N-leg) is:

$$R_P = \frac{\int_0^{l_1} \rho_1(l)\,dl + \int_0^{l_2} \rho_2(l)\,dl}{A_p} \qquad \alpha_P = \frac{\int_{T_{JP}}^{T_h} \alpha_1(T)\,dT + \int_{T_c}^{T_{JP}} \alpha_2(T)\,dT}{T_h - T_c} \tag{3}$$

Where R_P is the internal resistance of P-leg, $\rho_1(l)$ is the function that the electrical conductivity varies with length of material in high temperature region, and A_p is the cross section area of P-leg. $\alpha_1(T)$,$\alpha_2(T)$, stand for the function that the Seebeck coefficients vary with temperature in high and low temperature