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Efficiency Research on Thermoelectric Generator of Vehicle Exhaust

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Abstract: *The temperature of vehicle exhaust is high which carries off about 40 percent of the engine's total energy. Thermoelectric generation technology can convert waste thermal energy into electric energy for recovery and utilization. This paper introduces the basic principle of Vehicle exhaust thermoelectric generator.Optimizes the structure of heat exchanger and topology of thermoelectric module.Establishes the mathematical model of output power and conversion efficiency that is related to resistance ratio and surface length ratio.By simulation analysis, obtained the condition of maximum value of output power and conversion efficiency.*

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I. Introduction

By the end of 2017, there will be 310 million vehicles in China.,but the car's energy efficiency is only about 40 percent[1]. Other energy is emitted into the air by cooling water or exhaust fumes which leads to a huge waste of energy.Thereupon emission pollution and energy shortage are becoming more and more serious. Thermoelectric generation technology can convert waste thermal energy into electric energy for recovery and utilization. It not only saves energy, but also reduces automobile exhaust emissions. Its working process has the advantages of no wear, no noise, clean and so on. The disadvantage is that the inner space of the heat exchanger channel is large, and the heat of the tail gas can not be fully utilized. At the same time, the external surface temperature distribution is not uniform, which causes the thermal terminal temperature of the thermoelectric module to be inconsistent and affects the generation efficiency[2]. Therefore, the main direction to improve the generation efficiency of the thermoelectric generator is to select the thermoelectric materials with good performance and rationally arrange its topological structure and optimize the internal structure of the heat exchanger channel. This paper mainly research thermoelectric generator from two aspects: output power and conversion efficiency.

II. Basic Principle Of Thermoelectric Generation

The principle of thermoelectric generation is to use the Seebeck effect of thermoelectric conductors to convert the heat absorbed in the conductor into electric energy, without mechanical movement and physical or chemical changes. Thermoelectric module is composed of several thermocouples with a certain topological structure. In a single temperature thermocouple ,when temperature is difference between the high temperature surface and the low temperature surface, The internal cavitation part of P-type semiconductor migrates from the low temperature surface to the high temperature surface, The electrons transfer from the high temperature surface to the low temperature surface in N-type semiconductor. The free electrons in the PN junction flow generating the thermo-electromotive force.The thermo-electromotive force is related to the seebeck coefficient of the semiconductor material,the larger the seebeck coefficient is, the greater the thermo-electromotive force is. The formula is shown below[3] (1).

$$E=(\alpha_p-\alpha_n)*(T_h-T_c)=\alpha*\Delta T \quad (1)$$

In the formula, $\alpha_p$represents the seebeck coefficient of P-type semiconductor. α_n represents the seebeck coefficient of N-type semiconductor. T_h represents the temperature of the high temperature surface.T_c represents the temperature of the low temperature surface.

III. Model Establishment

Because the plate-type heat exchanger channel has a great influence on the pressure drop of the exhaust gas, the heat exchanger channel is designed as cylindrical channel in this paper. The model established by Solidworks, Fig.1. It consists of a cylindrical heat exchanger channel with a cross section of positive eight sides,sawtooth spoiler is welded inside the heat exchanger channel, as shown in Fig.2. A thermoelectric module is installed on eight outer wall surfaces of the heat exchanger, and there is an adiabatic layer between the thermoelectric modules, and the cooling water tank is used as a whole tank with inlet and outlet.

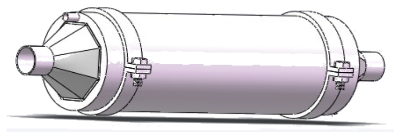

Fig.1. Module of thermoelectric generator of vehicle exhaust

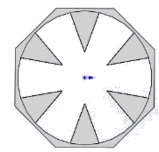

Fig.2.Sawtooth spoiler

IV. Efficiency Research On Thermoelectric Generator

Experiments show that, in the region of the same temperature, the power is higher when the thermocouple in series than parallel. So the series is used in the same temperature region. But the thermocouple is limited by the rated current, and when the current is too large it will damage the thermocouple. Therefore, shunt is carried out in parallel mode in different temperature regions on the same plane. The total length of the heat exchanger channel is 685mm, the inner diameter is 163mm, the thickness is 3mm, the inner diameter of the inlet and outlet of exhaust gas is 60mm, the length of the entry section is 50mm. The topology structure of thermocouple is 10X8, as shown in Fig.3. The model is shown in Fig.4.

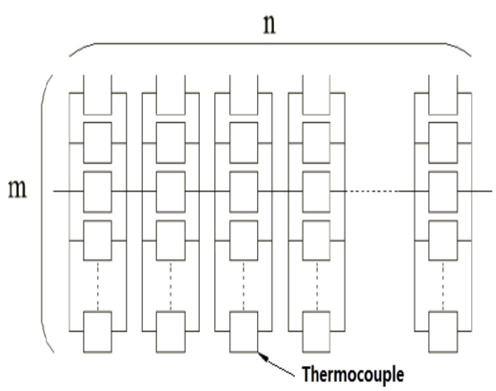

Fig.3. Topology

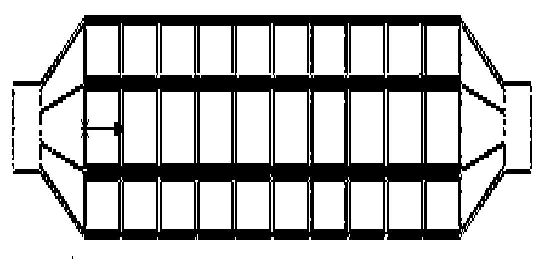

Fig.4.The thermoelectric module

Firstly, the theoretical output power and conversion efficiency mathematical model of single thermocouple are established. The thermocouple has its own parameter attributes. Its internal resistance is proportional to the resistivity and length,and inversely proportional to the cross-sectional area.The thermal conductivity is proportional to the resistivity and cross-sectional area, and inversely proportional to the height, as shown in formula (2)(3).

$$R = (\rho_P + \rho_n) l / A \tag{2}$$

$$k = (k_P + k_n) A / l \tag{3}$$

In the formula, ρp represents the resistivity of the P-type semiconductor. ρn represents the resistivity of the N-type semiconductor. kp represents the thermal conductivity of P-type semiconductor.knrepresents the thermal conductivity of N-type semiconductor.A represents cross-sectional area. l represents length.

Define external resistance and internal resistance ratio of a single thermocouple is m , Cross-sectional area and length ratio is f. Derived from formula (1) ,the current in a single thermocouple in the presence of a temperature difference is shown in formula(4). The output power of a single thermocouple is proportional to the external load voltage and current,then the theoretical output power mathematical model is shown in formula (5). The conversion efficiency of a single thermocouple is the ratio of the output power to the total absorption heat,then the mathematical model of theoretical transformation efficiency is shown in formula(6).

$$I = E / (R + R_L) \quad (4)$$

$$P = U_L * I = E^2 R_L / (R + R_L)^2 = E^2 / \left[\frac{(R - R_L)^2}{R_L} + 4R \right] \quad (5)$$

$$\eta = P / Q = \frac{\Delta T}{T_h} * \frac{m}{(1+m) + [(1+m)^2 / ZT] - \Delta T / 2T_h} \quad (6)$$

The thermoelectric module in this model is composed of several thermocouples with a certain topology structure. Based on the theoretical mathematical model, the output efficiency and conversion efficiency in this model are easily obtained, is shown in formula(7)(8). The above formula shows that both the output power and the conversion efficiency are the functions of the resistance ratio and the surface length ratio. Therefore, the influence of the surface length ratio and the resistance ratio on the output power and the conversion efficiency is analyzed by MATLAB.

$$P = \alpha^2 \Delta T m f \ / \ \rho (1+m)^2 \quad (7)$$

$$\eta = \frac{\alpha^2 \Delta T m f}{\rho (1+m)^2 [\alpha T_h \frac{\alpha \Delta T f}{\rho (1+m)} + k f - \frac{\alpha^2 \Delta T^2 f}{2 \rho (1+m)^2}]} \quad (8)$$

The above mathematical model is imported into MATLAB to simulate. Make the following assumptions about the computing conditions, set the number of thermocouples to 1, the high temperature is 230℃, the low temperature is 30℃, the physical parameters of semiconductor materials are shown in Table I.

According to the output power mathematical model, MATLAB calculation result is shown in Fig.5.Showing when internal resistance and external load is equal, that is m=1, the output power gets the maximum value. The output power increases linearly with the increase of the surface length ratio. When the cross section area of the thermocouple is fixed, the output power will be increased when the length of the thermocouple is shortened.

Table no 1 : The physical parameters of semiconductor materials

	P-type semiconductor	N-type semiconductor
α (V/ °C)	2.18e-04	-2.11e-04
k $(W / m \cdot k)$	1.5	1.65
ρ $(\Omega \cdot m)$	1.55e-05	1.35e-05

According to the conversion efficiency mathematical model, MATLAB calculation result is shown in Fig.6.Showing the conversion efficiency increases with the increase of the resistance ratio, and its growth rate is a trend of first increase and then decrease. The effect of the surface length ratio on conversion efficiency is very small and can be ignored.

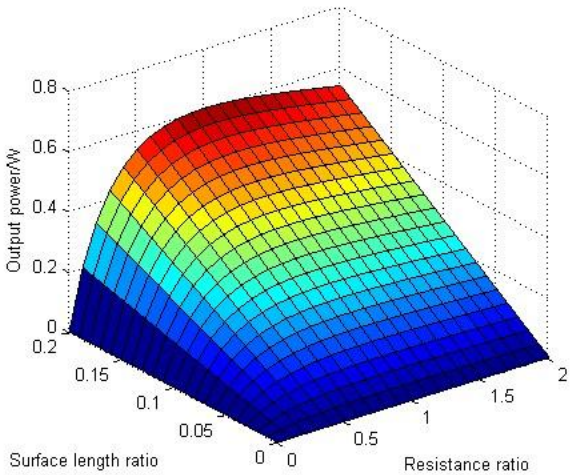

Fig.5. Simulation result of output power

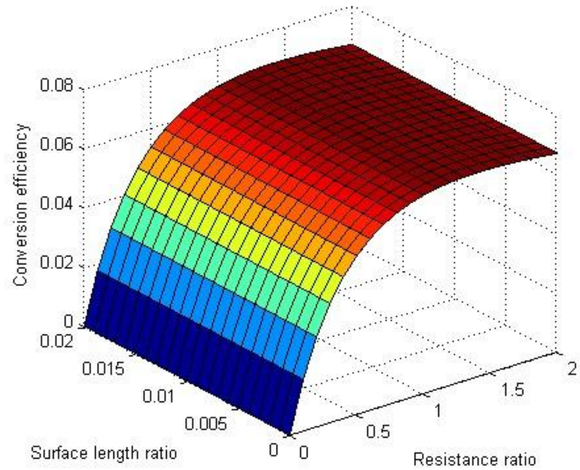

Fig.6. Simulation result of conversion efficiency

Under different temperature conditions,calculate the relationship between output power and resistance ratio, conversion efficiency and resistance ratio ,and then the calculation results are shown in Fig.7.and Fig.8. Showing when other parameters are fixed, the higher the temperature difference is, the higher the output power and the conversion efficiency is.

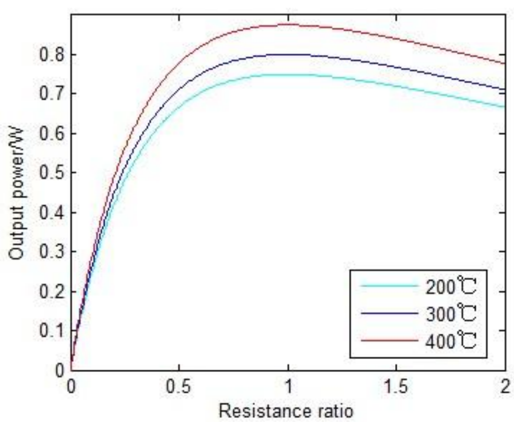

Fig.7. The output power under different temperature

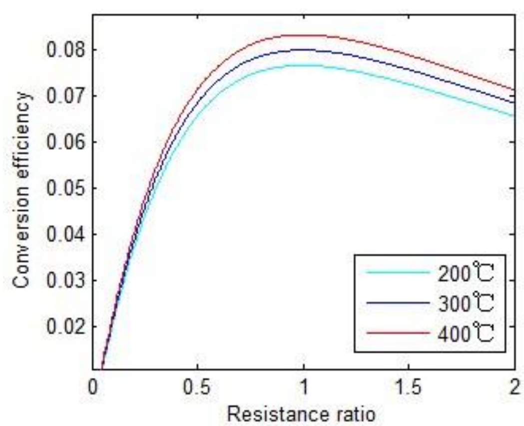

Fig.8.The conversion efficiency under different temperature

V. Conclusion

According to the model , researched on the relationship between output power and the resistance ratio,the surface length ratio,the relationship between conversion efficiency and the resistance ratio,the surface length ratio in a thermoelectric system. Obtained when internal resistance and external load is equal, that is m=1, the output power gets the maximum value,when $m = \sqrt{1 + ZT}$ the conversion efficiency gets the maximum value. The internal resistance with temperature change should be considered, the influence of the engine exhaust to temperature should be considered too, therefore, further research is needed.

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