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NUMERICAL SIMULATION OF THE INFLUENCE OF GAS CHANNEL SIZE ON THE PERFORMANCE OF THERMOELECTRIC GENERATOR

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ABSTRACT

Thermoelectric generator (TEG) technology has considerable potential in the recovery and utilization of waste heat of automobile exhaust. This paper simulated the thermoelectric generator by using the automobile exhaust waste heat in numerical simulation method. The numerical calculation shows that the total open voltage of the thermoelectric modules increases with the wall thickness increases when the length of exhaust gas channel is same as the length of all one-side thermoelectric modules. When the length of the exhaust gas channel increases, the open circuit voltage of the thermoelectric modules on the channel first decreases and then increases along the air inlet direction, and the total open circuit voltage of the thermoelectric modules also increases with the increase of the wall thickness of the exhaust gas channel.

Keywords: automobile exhaust; thermoelectric generator; thermoelectric module; exhaust gas channel

1. INTRODUCTION

With the development of the economy and the improvement of the quality of life, the demand for energy is increasing year by year. According to world energy consumption statistics, global energy consumption will increase by 2.3% annually, and it is predicted that from 2014 to 2035, energy consumption will continue to grow at an annual rate of 1.4%. Among all energy sources, fossil fuels represented by petroleum and coal still occupy a dominant position in energy consumption, and their proportion in primary energy consumption is as high as 86%. With the development of the automobile industry, the consumption of petroleum energy has been accelerated, and the exhaust gas emitted by automobiles has also seriously polluted the environment. In fact, the exhaust gas emitted by a car engine into the atmosphere takes away 40% of the energy released by fuel consumption. The exhaust temperature of automobile exhaust gas is usually 300℃ ~600℃. If this part of exhaust heat can be recovered and used, it will help improve the performance of automobile engines, reduce fuel consumption, reduce harmful gas emissions, and bring social and economic benefits[1]. How to use these waste heat has become a hot topic of current research. Some scholars have studied heating working medium by using waste gas heat, and some have researched generating electricity by applying the Rankine cycle, Brayton cycle or Stirling cycle[2-4]. In recent years, the research on using thermoelectric generators to recover the waste heat of automobile exhaust has attracted more and more attention. The thermoelectric generator is a solid-state energy conversion device, which can directly convert heat into electric energy. Compared with the power cycle, due to the simple structure, no rotating parts, and no working medium, the thermoelectric generator is more convenient to install and maintain. It is widely used for waste heat recovery and power generation. A large number of scholars apply it to the exhaust gas energy recovery system. However, due to the physical properties of the material, the current power generation efficiency is low. Therefore, improving the power generation performance of thermoelectric generator has become the focus of attention of scholars.

Thermoelectric power generation has been used in automobile exhaust energy recovery for more than 30 years. A large number of research institutions including BMW, HI-Z, Nissan and other car companies have carried

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out systematic research on exhaust thermoelectric power generation technology[5-7]. However, due to the high cost of thermoelectric generators and low thermoelectric conversion efficiency, the large-scale commercial application of exhaust thermoelectric power generation has not been realized. Therefore, reducing the cost of thermoelectric generators and improving the conversion efficiency of thermoelectric generators have become the key research contents in the field of automobile exhaust thermoelectric power generation[8].

Although there have been many years of progress in the use of automobile exhaust heat for thermoelectric conversion, the relevant basic research is not perfect, which restricts the popularization and application of waste heat recovery methods. This article intends to carry out thermoelectric generator research on automobile waste heat by means of simulation, reveal the influence of various factors, and provide a reference for the design of waste heat thermoelectric generator.

2. PHYSICAL MODEL

The layout structure of thermoelectric module is usually decided by the cold and heat sources type and system cooling method, commonly including plate type, drum type, etc[9]. This experiment lays these thermoelectric modules on the upper surface and the lower surface of the exhaust gas channel, which belongs to the plate type channel, as can be seen in fig. 1. (a) and (b). It is much supportive to the layout number of thermoelectric modules than other structures of the channel, and good for the installation of cooling water tank. The thermoelectric modules are arranged between the exhaust gas channel and the cooling water tank, which cooling water fills the entire tank by applying downstream way in order to achieve cooling effect.

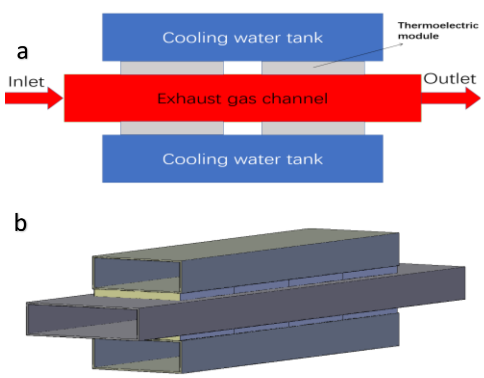

Fig. 1. (a) 2D diagram of TEG; (b) 3D diagram of TEG

The exhaust gas channel of the model is high 20mm, wide 70mm, long 350mm, the wall thickness of the channel were designed in five forms: 1mm、2mm、3mm、4mm、5mm, and the material is mainly stainless steel. The thermoelectric module is long 55mm, wide 55mm, high 5mm. There are 8 modules totally, four at the top and four at the bottom. As can be seen in fig. 1. (a) and (b), the model mentioned above selected FLUENT solver in GAMBIT to calculate, build the model and divide the mesh.

The model assumes that the fluid is an ideal condition and in a thermodynamic equilibrium state, so flow and heat transfer are controlled by the following continuous equation, momentum conservation equation and energy conservation equation:

Continuous Equation: $\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$

Momentum Conservation Equation:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2})$$

$$\rho\left(v\frac{\partial v}{\partial x}+u\frac{\partial v}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2})$$

$$\rho\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2})$$

Energy Conservation Equation:

$$\rho c_p\left(u\frac{\partial t}{\partial x}+v\frac{\partial t}{\partial y}+w\frac{\partial t}{\partial z}\right)=\lambda(\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}+\frac{\partial^2 t}{\partial z^2})$$

3. BOUNDARY CONDITIONS

Considering the model is turbulence model, it is necessary to select the standard k-ε equation when calculating. In order to ensure the convergence of the simulation iteration, it is appropriate to adopt the coupled implicit method. The pressure coupled with the velocity by adopting the SIMPLE algorithm, and the energy calculation residual is controlled in 10-6 order of magnitude.

(1)Inlet condition: given fluid velocity and temperature.

(2) Outlet condition: the outlet is pressure outlet.

(3) Solid wall condition: the wall material is stainless steel.

4. CALCULATION RESULTS AND ANALYSIS

In order to make an effective analysis for the results, models in different wall thickness were assumed to have same boundary conditions and cooling water tanks were assumed to have same cooling conditions during the simulation. Because the channel is symmetric, the results used for analysis came from four pieces of thermoelectric module from one side.

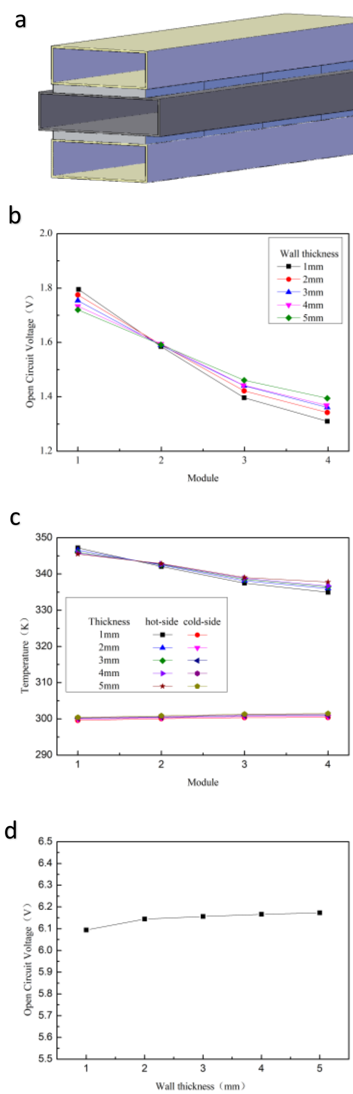

Fig. 2. (a) 3D diagram of TEG which the length of exhaust channel is the same as the length of four modules; (b) Open circuit voltage of TEG with different wall thickness; (c) Temperature of hot and cold side of TEG with different wall thickness; (d) Total open voltage of TEG with different wall thickness

Fig. 2 (a) shows a three-dimensional diagram of the TEG with the length of the gas channel equal to the total length of the four modules, from which can be seen that the inlet and outlet ends of the gas channel are flush with the thermoelectric modules. Fig. 2 (b) shows the open circuit voltages of four thermoelectric modules attached to the hot sides of the channels with different wall thicknesses. It can be seen from the figure that the open circuit voltage of the first thermoelectric module close to the gas inlet decreases with the increase of the wall thickness of the channel, but along the gas flow direction, the open voltage of the thermoelectric module increases with the increase of the wall thickness. As can be seen in Fig. 2 (c), when the wall thickness of exhaust gas channel is relatively thin, the hot side temperature of the first piece of module is relatively high, so the first module can absorb more heat accordingly and can finally give a higher open voltage. Along with the direction of air flow, the open voltage decreases quickly due to the heat absorbed by the following modules decrease gradually. But as the thickness of wall increases, even though the heat absorbed by the first piece of module is getting fewer, the rest of the heat still can be assigned to the following modules. Therefore, the open voltage of the following modules increases with the wall thickness increases. As can be seen in Fig. 2 (d), when the wall thickness is 5mm, although the open voltage of the first piece of thermoelectric module is the lowest, the total open voltage of four pieces of modules from one side is the highest.

Fig. 3(a) is the TEG which has been lengthened inlet and outlet of the exhaust gas channel, and the length of the channel is twice the length of the channel in Fig. 2(a). Fig. 3(b) shows the open voltage of the TEG with lengthened inlet and outlet of the exhaust gas channel. As can be seen from Fig. 3(b), instead of all the open voltages declining in turn, the open voltage of the fourth thermoelectric module is higher than the open voltage of the third and the second module, and the open voltage of the first module is much higher than others. Furthermore, as the wall thickness of exhaust gas channel has increased, the total open voltage of the TEG is getting higher.

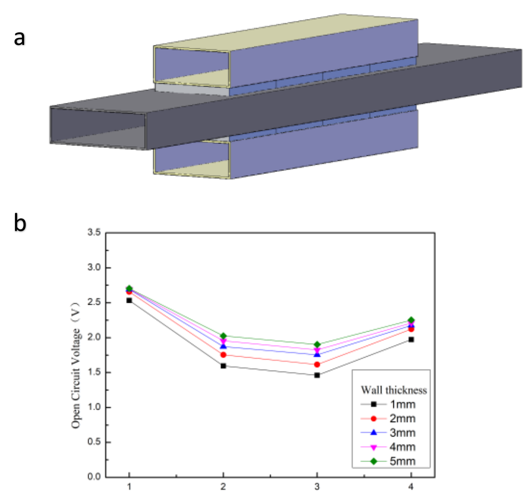

Fig. 3. (a) 3D diagram of TEG which the length of exhaust channel is twice the length of four modules; (b) Open circuit voltage of TEG with different wall thickness.

Fig. 4(a) shows the TEG with further lengthened exhaust gas passage, which length is three times the length of the channel in Fig. 2(a). Fig. 4(b) is the open voltage of the TEG with further lengthened exhaust gas channel. As can be seen from Fig. 3(b) and Fig. 4(b), the trend showed by curve in Fig. 4(b) is more obvious than the one in Fig. 3(b), and the total open voltage of the TEG in Fig. 4(b) is much higher than the one in Fig. 3(b). Analysis of the results shows the wall of the exhaust gas passage also plays a role in heat conduction. When the channel has been lengthened at inlet and outlet there will be a certain thermal effect on these two points. Hence, the thermoelectric modules near the inlet and outlet can absorb more heat to improve the thermoelectric conversion efficiency. The analysis also shows the wall of the exhaust gas passage plays a role in heat conduction with the wall thickness increases. Hence, the open voltage of the TEG increases with the wall thickness increases.

a

b

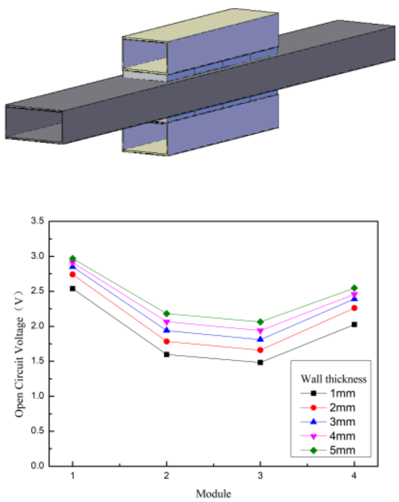

Fig. 4. (a) 3D diagram of TEG which the length of exhaust channel is three times the length of four modules; (b) Open circuit voltage of TEG with different wall thickness.

5. CONCLUSION

In this essay, the temperature between the hot and cold side of the whole thermoelectric modules from one side of the TEG as well as the open voltages of the same modules have been calculated by numerical simulation method under a certain inlet air flow and temperature.

The results show that when the length of exhaust gas channel is same as the length of all one-side thermoelectric modules, the open voltage of the first piece of thermoelectric module which is nearby the air inlet of channel decreases with the wall thickness of channel grows, but for other three modules from the same side, the open voltage increases with the wall thickness of the channel grows along the direction of air flow. This is because when the wall thickness of exhaust gas channel is relatively thin, the hot side temperature of the first piece of module is relatively high, so the first module can absorb more heat correspondingly and can finally give a higher open voltage. Along with the direction of air flow, the open voltage decreases quickly due to the heat absorbed by the following modules decrease gradually. But as the thickness of wall increases, even though the heat absorbed by the first piece of module is getting fewer, the rest of the heat still can be assigned to the following modules. Therefore, the open voltage of the following modules increases with the wall thickness increases. And the total open voltage of the TEG increases with the wall thickness increases.

When the length of the exhaust gas channel is twice the length of the channel in Fig. 2 (a), the open voltages of the thermoelectric modules at inlet and outlet is higher than the modules in middle due to the heat conduction effect of the lengthened part of the exhaust gas channel and the wall thickness. And the total open voltage of the TEG increases with the wall thickness increases. When the length of the exhaust gas channel is three times the length of the channel in Fig. 2 (a), the trend mentioned above will be more obvious, and the total open voltage of the TEG will be much higher than before.

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