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# Effects of Cooling Methods on Temperature of Thermoelectric Generators

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**Abstract:** In order to achieve the energy recovery of the Internal Combustion Engine (ICE) cooling system using the Thermoelectric Generation (TEG) technology, one test bed for studying the temperature of TEG is established then the relationship between the temperature and cooling methods is researched based on this test bed. The results show that the cooling effect improves with the increase of fan speed which is installed in the vertical direction of the radiator, but the cooling effect is no longer improved at a certain value of the speed because of the pressure loss. And it also indicate the forced air cooling is better than the natural convection cooling method which can effectively reduce the temperature of the cold end of TEG while has little effect on hot end.

**Key words:** Thermoelectric generation, temperature, cooling method, forced air cooling

## INTRODUCTION

Conventional Internal Combustion Engine (ICE) power conversion efficiency is only about 40%, as many as 60% of the fuel energy is dissipated in the form of waste heat into the air which cause a huge waste of energy (Liu *et al*., 2007). If this part of the energy can be recycled, the fuel economy and engine thermal efficiency will be improved effetely which has an important significance for energy conservation and environment pollution.

Thermoelectric generation technology (Thermoelectric generation, TEG) is a new kind of energy recovery technology which converts heat into electricity directly using the See-beck effect of thermoelectric materials. Therefore, based on thermoelectric conversion principle the engine exhaust gas heat and coolant heat can be recovered using thermoelectric generator. This kind of energy recovery technology has stable performance, no noise, no wear, small size, light weight, long life and other advantages which have catch more and more attention in recent years (Snyder and Toberer, 2008). Currently engine exhaust energy recovery has been paid more attention, including effect of thermoelectric structure (Liu and Zhang, 2006), cooling method (Hatzikraniotis, 2012; Yu and Zhao, 2007; Nuwayhid *et al*., 2005), the heat sink length (Chen *et al*., 2012) and radiator structure (Zhou *et al*., 2011; Casano and Piva, 2011; Dai *et al*., 2011) on the heat transfer efficiency of thermoelectric generator. While fewer researches has been done about coolant energy recovery and only one explore of using thermoelectric power generation to replace the radiator has been reported whose results show that the at the simulation speed of 80 km $h^{-1}$ the energy recovery efficiency was 3.2% at idle speed and energy recovery efficiency is up to 10%.

The main reason of fewer researches on coolant energy recovery is the cooling system temperature generally does not exceed 110°C which is much lower than exhaust gas temperature. However, in the view of engine heat balance, coolant energy is also considerable compared with the engine exhaust gas energy. Meanwhile the cooling system has cooling fans and pumps at the present which provides good premise for thermoelectric generation and the temperature limit of commercially available thermoelectric generation modules is 220°C which is higher than the coolant temperature without using special production. So, it is very convenient for practical application with commercial thermoelectric generator for coolant energy recovery.

The first thing for application of thermoelectric generation technology to energy recovery of engine coolant is to study the relationship of thermoelectric generation modules and temperature. Then one test bed is established based on engine coolant waste heat recovery and the influence of cooling method is investigated based on this test bed.

## TEST BED SET

The schematic diagram of the thermoelectric generation test bed is shown in Fig. 1, the system can

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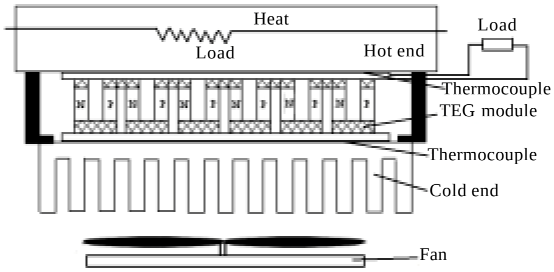


Fig. 1: Diagram of TEG module test

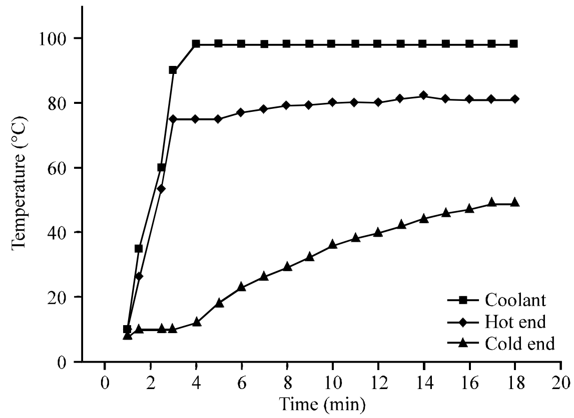


Fig. 2: Temperature trend during the coolant temperature rise

be divided into four parts (Zheng *et al*., 2006) the cold end, the hot end, the thermoelectric generation modules and the load. Among them, the cold end is made of aluminum and the dimensions (L×W×H) is 300×100×35 mm while the base thickness is 5 mm which is cooled with forced air by fan. The hot end is made of cast aluminum and the shape is box which can contain pure water for heating. The thermoelectric generation model type is F30345 and size is 40×40×3.8 mm whose internal resistance is 2.4 Ω. In order to measure the temperature of the cold and hot side the flat type K thermocouple is applied whose width is only 3.7 mm and thickness is 0.28 mm. The accuracy is ±1.5°C and the reaction time is 2.50 sec for this type thermocouple which is suit for measurement requirements. Meanwhile for increasing thermal conductivity and contact of the cold and hot end the silicone is used to connect the four parts.

Meanwhile, in order to measure the temperature of coolant and ambient respectively the K-type nickel-chromium-nickel silicon thermocouple is used. Then the processing circuit is applied for thermocouple and Altai's USB2002 acquisition system is also used for data acquisition. At the end the real-time recording temperature, voltage and other experimental data are imported into PC.

## RESULTS AND DISCUSSION

**Process of the temperature rise:** Figure 2 shows temperature trend of the hot end and cold end during the coolant temperature rise. It can be seen that the temperature rise process of the hot end has a same trend as the heating coolant during the heating process, but at the end the coolant temperature reaches 100°C while the hot end temperature was only 80°C. The reason is the aluminum container wall between the coolant and the hot end which causes a fixed thermal resistance between the two objects and produces temperature difference. Therefore, in practical applications this kind of thermal resistance should be minimized and the material with big thermal conductivity such as brass can be considered.

However, the rise trend of the cold end shows a significantly different chat during the heating process. From the figure it can be seen about 4 sec after the start of heating the temperature of the cold end was almost the same as the ambient temperature then the temperature rise with the coolant and at the end after 18 sec the temperature maintained at 49°C and remained unchanged.

The material of the thermoelectric generation modules cold and hot end is ceramic and the core material of the thermoelectric generation modules is semiconductor whose thermal conductivity is small while the cold end is connected with the radiator which cause the cold end remain the ambient temperature. But with the continuous heating process the cold end temperature rises slowly. It can be explained by the small distance between the hot and cold end and the contact of the thermoelectric generation modules. Because of the small distance between the hot and cold end the heat can be the surrounding air to the cold end and also can be transmitted through the thermoelectric generation modules even if their thermal conductivity is small. However, when the heat transmitted to the hot end is equal to the heat transferred to the heat sink the temperature does not raise.

**Effect of cooling methods on temperature:** From the above analysis, the temperature difference across TEG can be maintained at about 30°C using natural air cooling method. For generating more power larger temperature difference is needed. So in order to increase temperature difference across TEG the forced air cooling method is studied. The fan used in this test is voltage control and rated voltage is 12 V, therefore several different cooling

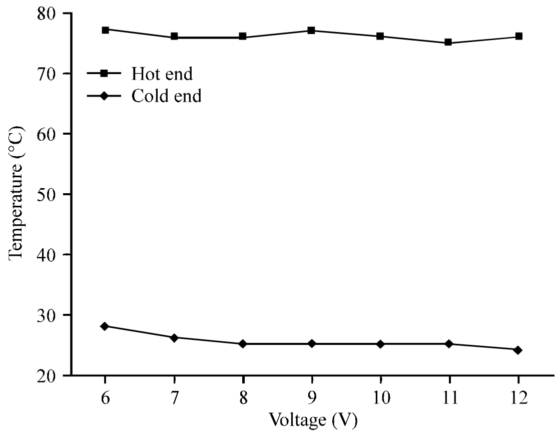


Fig. 3: Temperature of both end of TEG at different input voltages

effects in the analysis is simulated by changing the input voltage of the fan.

Figure 3 shows the temperature of both end of TEG at different input voltages of the fan. Compared with nature air cooling the temperature difference across TEG is significantly reduced by approximately about 24°C which can make the temperature difference reach 50°C or more. So it is obviously forced air cooling can increase temperature difference.

It also can be found that the hot side temperature is reduced by about 2°C although the cooling fan is located in the cold end. According to heat theory there are three ways for heat transmission: Heat conduction, convection and radiation and the heat conduction plays an important role in this test while the convection and radiation played a secondary role. The hot end heat obtained from the coolant is constant, the surrounding ambient temperature of TEG is reduced when the cold end temperature decreases obviously which enhance the heat conduction and convection in the form of heat transfer causing the hot side temperature slightly decrease.

It also can be found in Fig. 3 that the cold end temperature decreases to become inconspicuous when the fan voltage rises from 6-12V. Namely, forced air cooling can improve the cooling effect but there is a limit. When the limit is exceeded, the cooling effect becomes inconspicuous even if the air velocity increases.

The cooling method adopted in this test is axial fan plus radiator namely the jet cooling method which results the cooling air flow direction is at the vertical direction of the radiator. When the fan speed continues to increase the pressure loss is growing which will make pressure loss energy ultimately transfer to the heat sink in the form of heat conduction although the convective heat transfer will increase. Then the cooling effect improved is getting smaller and smaller with the increase of fan speed (Zheng *et al*., 2006).

## CONCLUSION

Based on the test bed the relationship between the temperature difference and cooling methods is studied and the following conclusions can be reached:

- The forced air cooling method can effectively reduce the temperature of the cold end and has little influence on hot end of TEG
- Using the axial fan plus radiator cooling method has a speed limit and the cooling effect is almost unchanged with the increase of rotational speed when the fan speed reaches the limit

## ACKNOWLEDGMENT

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