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Experimental Study on Effect of Operating Conditions on Thermoelectric Power Generation

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Abstract

Effect of boundary conditions of thermal reservoirs on power generation of thermoelectric modules (TEMs) is examined experimentally. To realize the characteristics of the power generation by the TEMs, the system performance is studied over various volumetric flow rates and flow temperatures of the hot gas and in the heat sink over a wide range of electrical load. The results show a significant influence of forced convection produced by an axial fan in the heat sink in comparison with natural convection. Also, both of the temperature and volumetric flow rate of the hot gas have a substantial effect on power generation by the TEMs. Lower volumetric flow rate in the heat sink is suggested to save fan power because it is found that higher volumetric flow rates on the cold side after the optimal flow rate does not have much effect on the power generation by TEMs. The maximum power produced by tested TEMs is 4.59 W at temperature difference equal to 133.78°C.

*Keywords:*Forced and Natural Covection; Thermoelectric Module; Experimental Study; Power Generation.

1. Introduction

Some special features like having no moving parts, having long life time, being highly reliable, silent operation and being environmentally friendly make TEMs a good alternative energy technology to decrease dependency on fossil fuels. As TEMs do not need fuel supply and also their low maintenance requirements they can be a good choice for energy harvesting via the direct recovery of waste heat and conversion into useful electrical energy. Applying TEMs to improve the efficiency of waste heat recovery by using different heat sources such as geothermal

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energy, power plants, automobiles and other industrial heat-generating process is an interesting subject in studies [1–4]. Hsiao et al [5] developed a mathematic model of TEM to comprehend the characteristics of thermoelectric generator (TEG), and the effects of engine speed and coolant temperature of radiator on the TEM. Output power and thermal efficiency of TEG at different coolant temperatures were presented. Commercially available Bi_2Te_3 thermoelectric cells were examined by Ding et al [6] in different operating conditions. Performance and reliability of TEGs for power generation were presented. Performance of these TEGs when subjected to thermal cycling and continuous operation at hot side temperature of about 160°C was also investigated. The results showed that commercially available TEG tested is reliable to be used under thermally cycled hot side temperature <90°C and cooled at ambient temperature, for at least 500 cycles as tested. An experimental and numerical study on low-temperature waste heat harvesting with 24 TEGs to convert heat from the exhaust pipe of an automobile to electrical energy was carried out by Hsu et al [7]. Open circuit voltage and output power of the system were presented for variant temperature differences. The performances of TEMs at different operating conditions were investigated by Chen et al [8]. Flow patterns, heating temperatures, flow rates of water and numbers of modules were examined experimentally. They found that heating temperature is the most important parameter in the performance of the TEMs and the effect of the other factors are not significant. Rezania et al [9] studied and optimized a micro plate-fin heat exchanger applied to a TEG to maximize the output power and the cost performance of generic TEG systems. They showed that there is a unique pumping power that delivers the maximum cost performance for the TEG systems. To study the effect of complex vehicle driving conditions on the TEG performance, a numerical model of TEG based on vehicle waste heat recovery was developed by Yu et al [10]. They found that the performance variation of TEGs becomes more remarkable with faster acceleration or deceleration. Meanwhile in deceleration the transient response of the hot and cold side temperatures, voltage and power is less significant in comparison with acceleration.

This experimental study aims to find TEMs electrical response to variation of thermal boundary conditions. The effect of volumetric flow rate and the temperature of the exhaust gas, and the effect of variation of the volumetric flow rate in the cold side of the TEMs are tested. Furthermore, in the cold side a comparison between natural and force convection has been studied.

2. Experimental setup

The schematic diagram of the experiment setup is shown in Fig. 1(a). An axial fan with variable power supply is used for cooling the cold side and a hybrid system including a hot gas supplier and a constant temperature reservoir is applied for heating the hot side of TEMs. T-type thermocouples are used for measuring temperatures of the hot and cold sides and also the ambient temperature. Four thermocouples are located on each side of the finned plates just behind of the modules. All the temperatures are monitored continuously in a PC by a data acquisition system. A programmable DC electronic load device is used for applying load to the TEMs. The test section consists of a thermoelectric generator made of four TEMs connected electrically in series. The commercially available Bi_2Te_3 based thermoelectric modules with a module size 30mm×30mm×4.2mm is used for the experiments. As it is shown in Fig. 1(b), TEMs are inserted between two finned plates as conventional heat sink and heat source with the same areas (100×100 mm). The finned surface consists of 17 fins with thickness 2 mm and height 30 mm. The gap between the fins is 2 mm.

3. Results and discussion

Corresponding to equation 1, for obtaining the absolute value of the internal resistance of the TEG, the slope of the V-I linear lines should be calculated. Fig. 2(a) shows the V-I curves in different temperature differences.

$$V = RI \tag{1}$$