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Experimental Analysis and Performance Optimization of Thermoelectric Generator

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***Abstract*: Nowadays the world has experiencing global warming due to excessive energy release into atmosphere. A lot of research being conducted on ways to recover or reused the waste energy. Thermoelectric power generator has emerged as a promising alternative green technology due to their distinct advantages. The current work presents an experimental investigation and optimization of a thermoelectric module to find the effect of the main operating conditions. The experimental result shows that the thermoelectric generator power out increases with increasing temperature differences and mass flow rate of water. The maximum power output is obtained when internal resistance of the thermoelectric module matches with applied load resistance.**

***Keywords*: Heater, Thermo electrical generator, Thermo electrical module, Waste heat.**

1. Introduction

The common technologies used for waste heat recovery from engine include thermo- electrical devices, organic Rankin cycle or turbocharger system. By maximizing the potential energy of exhaust gases, engine efficiency and net power may be improved. Energy efficiency is a concept which helps to obviously show the environmental impact by numbers. By increasing the energy efficiency, sustainability index will increase and leads to less production of pollutants like NOx and SO2 during creating the same amount of power [1]. Thermoelectric power generation has emerged as a promising alternative green technology [2].

Thermoelectric waste-heat recovery technology could potentially offer significant fuel economy improvements. If this is demonstrated feasibly on large scale applications such as automobiles, a significant savings in worldwide fuel consumption can be achieved by applying the technology across the board to conventional and hybrid vehicles [3]. A multidisciplinary approach will be required to develop higher-efficiency thermoelectric materials and devices. The many materials yet to be investigated, there is certainly much more work ahead and promise for developing higher-efficiency thermoelectric materials and devices [4].

Research in both enhancing figure of merit (ZT) and reducing cost is needed. Practical thermoelectric device need both n-type and p-type material with comparable ZT but p- type bismuth telluride super lattices have much higher ZT values then n-type bismuth telluride super lattices [5]. Thermoelectric modules consist of oxide legs possessing good electrical and mechanical properties. Unfortunately, their conversion efficiency is lower than conventional TE modules [6]. Thermoelectric modules (TEMs) and cooling systems can produce the higher, stable, and efficient power energy. The proposed water based cooling system has advantages in term of stability as well as capability to maintain the temperature different between hot and cool side of the TEM [7]. Thermoelectric generator system working at the exhaust pipe for various operation conditions, including (1) the configuration of the heat absorber; (2) the inlet temperature of hot fluid (3) the flow rate of hot fluid and (4) the flow rate of cooling air [8].

The open circuit voltage (V_{oc}) is increased linearly with temperature difference and power (P) output is increased rapidly with increasing the temperature difference. The V_{oc} and the P_{max} are expressed as a function of temperature difference, which helps to forecast the system performance as temperature difference > 30 K. For this system to harvest waste heat, the maximal power output is observed in the range of matched load of 23–30 X with increasing T_h from 323 to 403 K [9]. The maximum power output and the corresponding conversion efficiency are greatly affected by the operating conditions, especially the hot fluid inlet temperature and flow rate [3].

2. Thermoelectric Materials

Thermoelectric materials (those which are employed in commercial applications) can be conveniently divided into three groupings based on the temperature range of operation. Alloys based on Bismuth (Bi) in combinations with Antimony (An), Tellurium (Te) or Selenium (Se) are referred to as low temperature materials and can be used at temperatures up to around 450K. The intermediate temperature range up to around 850K is the regime of materials based on alloys of Lead (BP) while Thermo-elements employed at the highest temperatures are fabricated from SiGe alloys and operate up to 1300K. Although the above mentioned materials still remain the cornerstone for commercial and practical applications in thermoelectric power generation, significant advances have been made in synthesizing new materials and fabricating material structures with improved thermoelectric performance. Efforts have focused primarily on improving the material's figure-of-merit, and hence the conversion efficiency, by reducing the lattice thermal conductivity.

There are challenges in choosing suitable materials with sufficiently higher ZT for the applications. The best thermoelectric materials defined as ‘‘phonon-glass electron-crystal’’, which means that the materials should have a low lattice thermal conductivity as in a glass, and a high electrical conductivity as in a crystal.

Table 1
Temperature classification of thermoelectric materials

Material composition Further components	Low Temp.	Intermediate Temp.	High Temp.
	(300-450 K)	(450-800K)	(800-1300K)
	Bi	PbTe	SiGe
	Sb, Te, Se		

3. Experimental Setup

The experimental equipment is consisted of:

1. Heat source, 2. Plate type heater, 3. Heat sink (heat exchanger), 4. TEG module.

The external heat sink, fixed to the cold sides of thermoelectric generators for forced convective cooling, was made of aluminum alloy. The configuration and dimension of the heat sink is shown in Fig. 1.

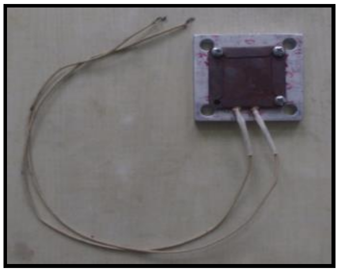

Fig. 1. Heat source

Plate type heater can heat the aluminum plate to the rated temperature within a short period of time.

Fig. 2. Plate type heater

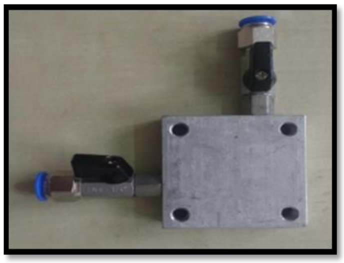

Fig. 3. Heat Sink

The other sides (cold sides) of the thermoelectric generators were affixed to the external heat sink for cooling. The temperature difference between the cold and hot sides of thermoelectric generators increases with the heat transfer rate, so that a better heat-transfer design will obtain higher generating electricity.

This experiment used the thermal grease (shown in fig. 4) with high thermal conductivity to affix the hot sides of thermoelectric generators to the heat absorber, so as to transfer the heat energy to the thermoelectric generators.

Fig. 4. Thermal Grease

The modules will generate electricity there in temperature difference cross the modules. So, you need to attach one side of the modules to a heat source and the other side to a cool source like heat sink to dissipate the heat coming from heat source through the modules.

Table 2 shows the specifications of the thermoelectric generator made by Gayathri Krishna. The thermoelectric generator uses the temperature difference between both sides of the chip module to convert the heat energy into electric energy.

Table 2
Specification present thermoelectric generator module (TEG SP1848-27145 Gayathri Krishna)

<table>
<tr><td colspan="6">Dimensions 40 X 40 X 3.7 mm
</td></tr>
<tr><td>Temp.(^{0}C)</td><td>20</td><td>40</td><td>60</td><td>80</td><td>100</td></tr>
<tr><td>Voltage(V)</td><td>0.97</td><td>1.8</td><td>2.4</td><td>3.6</td><td>4.8</td></tr>
<tr><td>Current(mA)</td><td>225</td><td>368</td><td>469</td><td>558</td><td>669</td></tr>
<tr><td colspan="6">Number side is exposed to heat and opposite side is exposed to cool below 5-250C</td></tr>
</table>

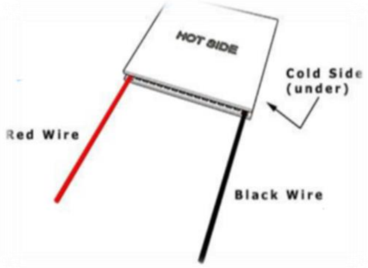

Fig. 5. TEG Module

Our module is single and different to others. The modules have cold and hot sides. You should attach the cold side to heat sink or heat exchanger, and hot side to heat source.

A. Assembly of Thermoelectric generator

- On the cold plate heat exchanger Thermal grease is applied.
- On the cold plate heat exchanger Cold side of thermoelectric module placed.
- On other side of hot plate Thermal grease is again pasted which is put on the hot side of the thermoelectric module with the help of fastening (Nut and bolts).
- Thermoelectric module is placed between hot plate and cold plate heat exchanger.
- On the upper side of hot plate Heater is fixed with screws which is connected to volt meter and ammeter. The voltage is controlled by dimmers tat.
- Temperature sensors are fixed at the interfaced of heat exchanger and thermoelectric module.
- Water is used as a cold fluid to control/ maintain constant temperature at cold side of heat exchanger.
- Thermoelectric generator is connected with rheostat and multi-meter to measure current, voltage and resistance of DC current which is generated by thermoelectric generator at various temperature differences.

Figure 6, shows thermoelectric generator connected with multi meter and rheostat.

Fig. 6. Thermoelectric generator connected with multi-meter and rheostat

4. Results and discussion

The variable parameters includes: the hot plate temperature; mass flow rate, and water temperature. The temperature of hot plate is controlled by voltage supply. The thermoelectric module is working at temperature difference between 20 to 120 ^{o}C. Cooling side temperature should not exceed by 30 ^{o}C. In order to evolve performance characteristics of system following graphs were plotted and studied. At mass flow rate of water 0.006 Kg/s, the power output decreases with increasing load resistance (5 ohm to 100 ohm). The fig. 7, shows that maximum power output as 0.648 Watt at temperature 240 ^{o}C. The power output increases with increasing heater temperature from 145 ^{o}C to 190 ^{o}C to 240 ^{o}C. Fig. 8 and 9, indicates that the power output increases with increasing mass flow rate of water. The maximum power output obtained at maximum heater temperature, maximum water mass flow rate at 5 ohm applied resistance.

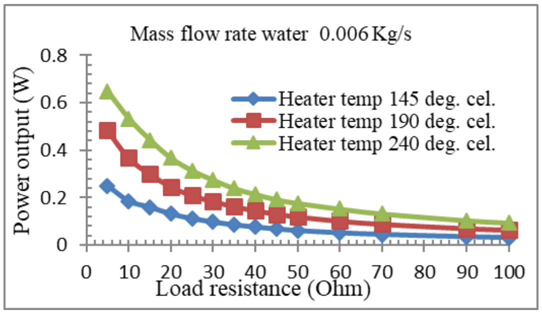

Fig. 7. Power Output vs. Load Resistance at mass flow rate 0.006 kg/sec

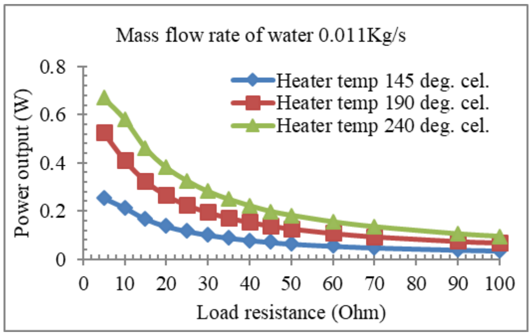

Fig. 8. Power Output vs. Load Resistance at mass flow rate 0.011 kg/sec.

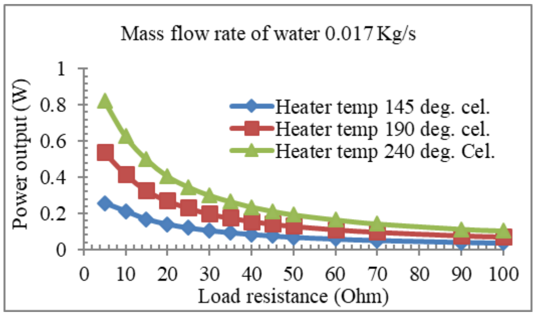

Fig. 9. Power Output vs. Load Resistance at mass flow rate 0.017 kg/sec.

5. Conclusion

Thermoelectric power generation offers a promising technology in the direct conversion of waste-heat energy, into electrical power. Waste heat powered thermoelectric generators are utilized in a number of useful applications due to their distinct advantages. Thermoelectric (TE) material should have a low lattice thermal conductivity and a high electrical conductivity as in a crystal. This study developed an integral thermoelectric generator system with high performance of thermoelectric generator. Water is used as a cold fluid in cold side of heat exchanger also studied effect of various operating conditions on performance of thermoelectric generator. The output power of thermoelectric generator increases with increasing temperature differences and mass flow rate of water.

The maximum power output, 0.83 W obtained at heater temperature 240 ^{o}C and applied resistance 5 ohm. When applied load resistance equal to the internal resistance of thermoelectric module, the maximum output power obtained.

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