"EXPERIMENTAL INVESTIGATION OF THERMOELECTRIC GENERATOR"

Minesh Vohra[1], Sanjeev Kumar[2]
[1,2] Assistant Professor, Lovely Professional University, Phagwara, India

Abstract

In an IC engine, 30% of the fuel energy is wasted in exhaust gases, and. Efforts are made to capture this 30 % energy of exhaust gases using TEG module. The present study covers the performance evaluation of thermoelectric modules without fin. Hence the module is fabricated and the efficiency of thermoelectric generator comes out to be 3.178%. Similarly, the efficiency of the fin which can be used along with this TEG is around 91%. The efficiency of thermoelectric is very low and its efficiency can be improved by utilizing high conductivity materials and using coolant at the cold surface.

1. INTRODUCTION

A thermoelectric generator is device that converts thermal energy (heat) to electric energy based on the "Seebeck effect" Seebeck effect states that if there is a difference in temperature between two different conductors or semi-conductors then a potential difference between the two materials is produced. [1] D. Champier et al., Studied a thermoelectric incorporated in a multifunction wood stove and concluded that adding TE (thermoelectric) generators can provide electricity up to 9.5 W. [2]Cheng-Ting Hsu, Gia-Yeh Huang, et al., [2011], Using a network of 24 thermoelectric generators (TEG) to convert heat from an automotive exhaust pipe to electric power. Based on simulation tests, a slopping block is designed to uniform the interior thermal area, which improves the efficiency of TEG modules. Thus, the result suggested the fundamental development of the thermoelectric generator device for low-temperature waste heat. [3] Yuchao Wang, et al. [2013] studied and represented a numerical approach to Thermoelectric Generator (TEG) system using vehicle exhaust gas as a heat source based on Fourier's law and the Seebeck effect shows that the height of the PN couple varies, The peak value of the output power decreases as the thermal conductivity of the PN pair decreases and increases when the Seebeck coefficient and the material's electrical conductivity increases. [4] Nguyen Q. Nguyen, et al. [2013] describes the power generation behavior of a thermoelectric generator (TEG) exposed to a hot-side transient heat source and natural cold-side convection, and shows that the presence of the Thomson effect plays a significant role in predicting accurately the power produced by the system. [5] Shiho Kim [2013] derived an analytic model describing the interior temperature difference as a function of the load current of a thermoelectric generator (TEG); and results specified that the effective internal electrical resistance was improved by approximately 5 % by the use of a 3.52 W / K thermal conductance module and a 50 W / K thermal conductance, but the effective Seebeck coefficient was attenuated by approximately 13 %. [6] A. Rezania et al. [2013, the heat exchanger was designed to optimize the output power instead of making adjustments in the TEG material using a micro plate-fin heat exchanger. They mainly worked on the channel width, channel height, heat exchanger fine thickness, there are different channel width and fine thickness values that provide maximum output power in the TEG. The result showed that there is a specific pumping power that

maximizes the cost efficiency of the TEG systems and that the micro-heat sink is in good agreement with the experimental data. [7] N. Wojtas, et al. [2013] used a coupling of TEGs to increase the output power of thermoelectric generators (TEGs) in order to make them more efficient and the result indicated that the use of TEGs coupling and micro fluidic heat transfer system gives the net output power of 126.3 mW/cm^2 was achieved with ZT of 0.1 at ΔT of 95K. [8].A.P. Perez-Marín et al. [March 2014] build Si-based micro thermogenerator using standard CMOS processing which resulted into the output power density of 4.5 µW/cm^2, under a temperature difference of 5 K. [9] Bekir S. Yilbas, Ahmet Z. Sahin [July 2014,] combined thermal system consisting of a thermoelectric generator and a refrigerator is considered and the performance characteristics of the combined system is investigated and found that the position of the thermoelectric generator between the condenser and the evaporator decreases the combined system's performance coefficient, but the position of the thermoelectric unit between the condenser and its atmosphere increases the combined system's performance coefficient. [10] Xiaodong Jia, Yuanwen Gao, using segmented thermoelectric generator (STEG) to achieve high efficiency under a large difference in operating temperature. The results indicate that certain segmented cases do not meet the strength criteria for a given operating temperature.

2. EXPERIMENTAL SETUP

2.1. Assembly: The both surfaces of the TEG module are covered with thermal paste of compound bismuth telluride. The hot face is attached to a aluminium surface to give a controlled input of heat. The heat flows from aluminium plate to the surface of TEG Module. A heat sink made of copper is attached to the cold surface to spread the heat content and create the temperature difference across the 2 surfaces of the module. Fins made of copper material with rectangular cross section are mounted on the copper plate to boost the transfer of heat to the surroundings. The assembly of these components is held together by means of nuts and bolts. Finally, the electrical output is used to drive the DC motor which in turn rotates the fan mounted on its shaft. In this manner the heat input is converted into electrical output which is received as the rotation of DC motor.

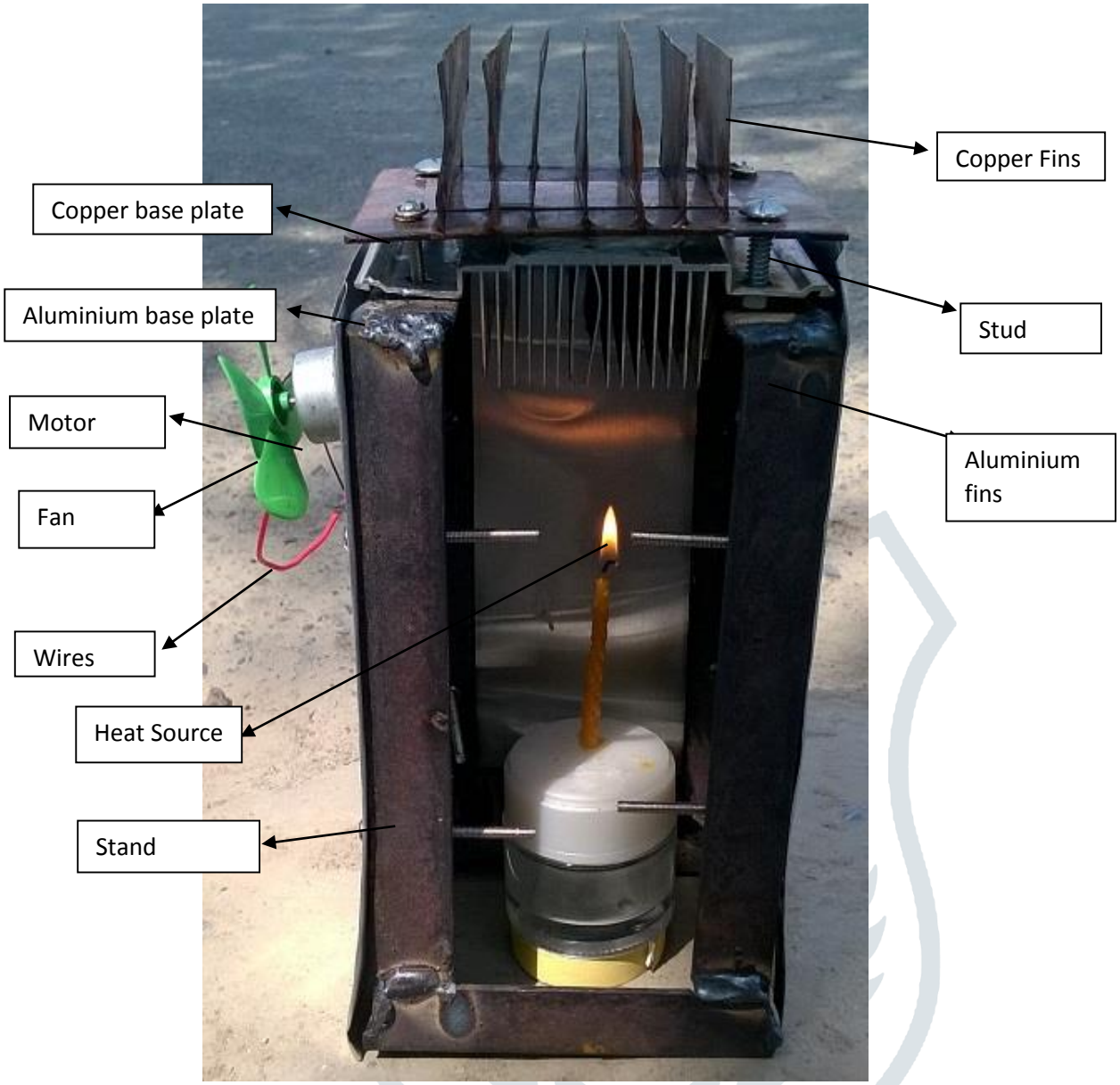


Fig: -Thermoelectric Module Integrated with Fins

2.2 Components Used: -

2.2.1. Copper base plate and fins (cold side): - 120 x 80 mm: the heat sink part is made up of copper because copper has high thermal conductivity(k). The thermal conductivity(k) of copper is 398 W/mK. The melting point of copper is 1084.62 °C. Due to high thermal conductivity it rejects the heat at faster rate compared to other metal. The second advantage of using copper is that it is economic and easily available compared to silver which has high thermal conductivity compared to copper.

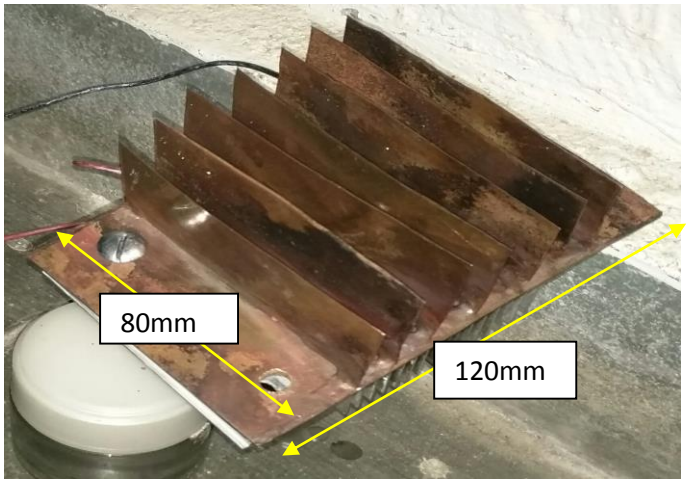


Fig 2.1: - Copper Based Heat Sink with Rectangular Fins

2.2.2. Aluminium base plate (hot side) 120 × 80 mm: - We used aluminium as the base metal for heating. The TEC module will be damaged if we will heat it directly, so aluminium is attached to the TEC module and the heat is supplied indirectly to the TEC module. Aluminium metal's thermal conductivity is 237 W / mK and aluminium's melting point is 660.3 ° C

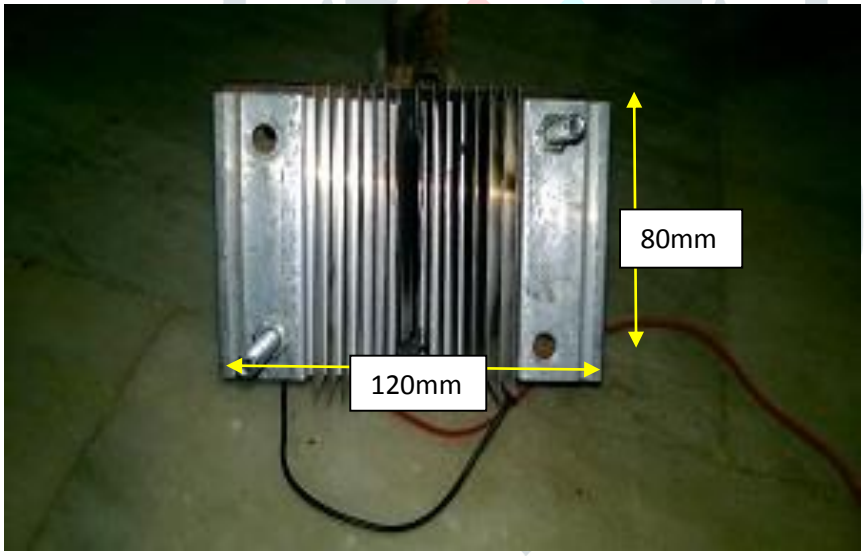
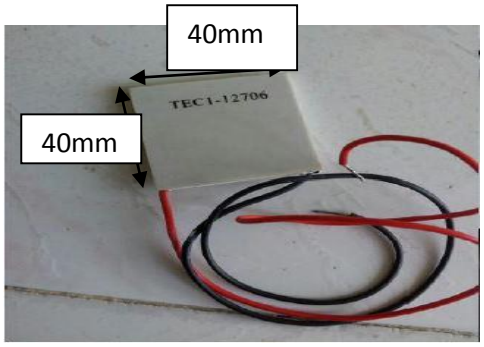


Fig 2.2: - Aluminium Base Plate

2.2.3. TEC-Module: TEC1-12706T125 (40×40×3.8mm):



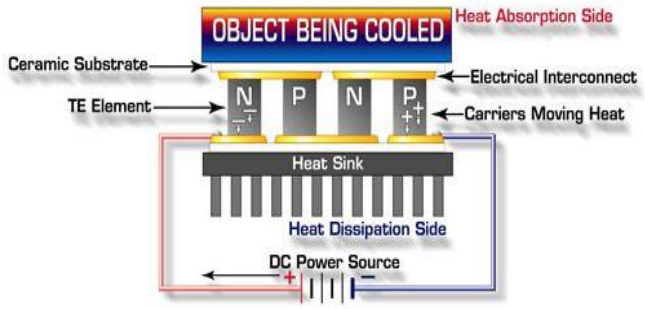


Fig 2.3: - TEC Module TEC 1 -12706 **Fig 2.4: - Circuit Within TEC Module**

The heat moves in one direction towards the cooler side while the electric current moves back and forth between the top and bottom substrates through factor N and P.

Table 1. Properties of single stage TEC module

Part Number	Couples	I_{max} (Amp)	V_{max} (V)	Q_{max} (W)	T_{max} (°)	Dimensions L x W (mm)	Height (mm)	Resistance (Ω)(ohm)
TEC1-12706	127	12	15.4	92.4	68	40 x 40	3.50	0.85

2.2.4. DC Motor: 1.5-3V: - Motors are of two type A C motor and D C motor. In this project we use D C motor.

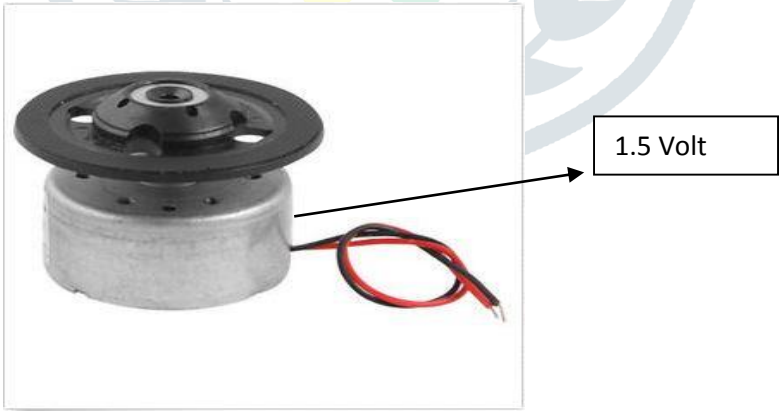


Fig 2.5: - DC motor

2.2.5. Small Fan with hub: - A small plastic fan is mounted on the dc motor for compensating the load on the TEG module.

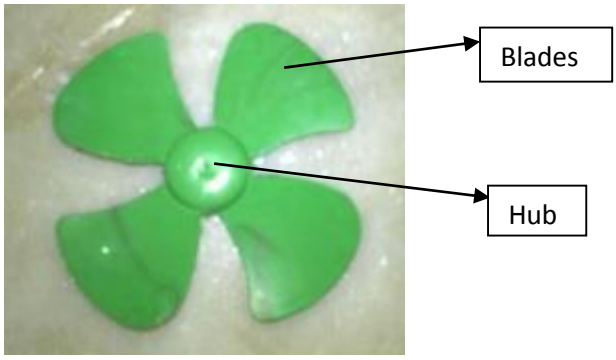


Fig 2.6: - Fan with Wings Made of Plastic

2.2.6. Thermal Paste (Arctic MX-4):- Thermal paste is a very high heat conductive paste that is used between two objects to get better heat conduction. It is commonly electrically insulating. It is usually applied as an interface between heat sinks and heat sources. As we know air is very poor conductor of heat and is usually trapped in the microscopic imperfections of the heatsink so thermal paste is applied to enhance the heat conduction. Thermal paste can be up to a 100 times greater conductor of heat than air but too much thermal paste will obstruct a heat sink's ability to cool properly.

Fig 2.7: - Thermoelectric Paste (Arctic MX-4)

2.2.7 Four piece of stud with threads: - Studs are basically a large-headed piece of metal that pierces and projects from a surface. It is used to attach the assemble together. Thread are made on the surface of the stud so that the nut can be attached from the other side. Metal stud are used because it can sustain high temperature.

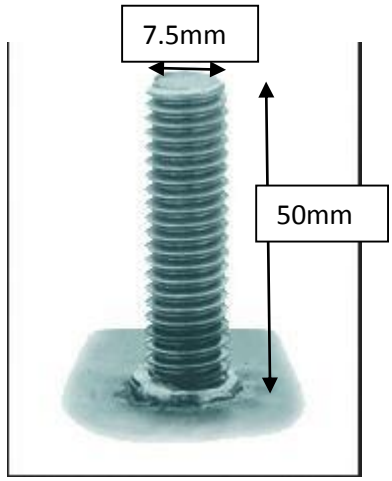


Fig 2.8 :- metallic stud

3. FORMULATION AND CALCULATIONS

3.1. Efficiency calculations of the TEG

As the module is given heat input, the temperature of the hot plate rises and heat is transferred to the other face of the TEG module. The following readings were noted for the TEG module: -

Temperature of hot surface, T_H = 70° C = 343 K

Temperature of cold surface, T_C = 48° C=321 K

Voltage (short circuit), V_o = 1.70 V

Voltage (under load), V = 0.163 V

Current (I) = 3 A

Thus, we have,

$$V_O = \alpha \times \Delta T \quad [21] \tag{1}$$

Where,

α = see beck coefficient

ΔT = temperature difference across the couple= T_H - T_C

$$1.70 = \alpha \times (70 - 48)$$

See back coefficient (α) = $\frac{1.70}{22}$ = 0.07727 V/K

Using the current relation [21],

$$V = \frac{\alpha \times \Delta T}{(R_L + R_C)} \tag{2}$$

Here, R_C = internal resistance of module

$$R_L = \text{Load resistance} = \frac{V}{I} \quad (3)$$

$$\text{Hence } R_L = \frac{1.63}{0.03} = 53.33\ \Omega$$

Substituting the values,

$$1.63 = \frac{0.07727 \times 22}{(R_C + 53.33)}$$

$$R_C = 3.33136\ \Omega$$

Now the total heat input (Q_H) is given as:

$$Q_H = (\alpha \times T_H \times I) - (0.5 \times I^2 \times R_C) + (K_C \times \Delta T) \quad (4)$$

$$Q_H = 15.3840 \text{ W}$$

Efficiency,

$$(\eta) = \frac{V \times I}{Q_H} \quad (5)$$

$$\eta = 3.1786\%$$

3.2. FINS & IT'S CONFIGURATION

A fin is a surface that extends from an object to increase the rate of heat transfer to or from the environment by increasing convection. Rectangular straight fins are very common fin geometry because of their simplicity to manufacture.

Fig 4.1: - Rectangular Fins Made of Copper

3.2.1 Fin Geometry: -

In our project we used thin and closely spaced fins made of copper. They have a rectangular cross section area and the specifications are given as: -

Face width of fin (W) = 8.5 cm

Thickness of fin (T) = 2.8 mm

Thermal conductivity of copper (k) = 400 W / m K

Convective heat transfer coefficient (h) = 17 W / m^2 K

Using the relation for design of rectangular fins, [22]

$$Sin\,h\left(2\,A_p\sqrt{(2\,h\,/\,k)}\,.\,T^{-3/2}\right)=6\,A_p\sqrt{(2\,h\,/\,k)}\,.\,T^{-3/2} \quad (6)$$

The above equation gives graphical solution as

$$A_p\sqrt{(2\,h\,/\,k)}\,.T^{-3/2} = 1.419 \quad (7)$$

Here,

A_p is the profile area given by Length (L), x thickness (T),

$$L/T\sqrt{(2\,k.T/h)}=1.419$$

Substituting the values, we get,

Length (L) = 25.74 mm

This is the required length of the fin.

Efficiency of the fin (η): - Efficiency $\eta=\dfrac{tan\ h\ ml}{ml}$ (8)

$$m=\sqrt{\frac{2\,h}{k.t}}$$

$$m=\sqrt{\left(\frac{2\times17}{400\times0.28}\right)}$$

$$m=0.55$$

$$\eta=\frac{tan\ h(0.55)}{0.55}$$

$$\eta = 0.91 \quad \text{or } 91\ \%$$

4. RESULT AND DISCUSSION

The performance of the thermoelectric Generator has been calculated in terms of efficiency. The efficiency of thermoelectric generator is 3.178%. The efficiency of thermoelectric is moderate and its efficiency can be increased by using different materials and using the coolant at the cold surface. Similarly, the efficiency of the fin is 91% and it can be varied by changing the dimensions of the fin. Thermoelectric generator improves the overall working performance of the automobile and all the system where heat is lost as a waste.

REFERENCES

1. Champier, Daniel, et al. "Study of a TE (thermoelectric) generator incorporated in a multifunction wood stove." Energy 36.3 (2011): 1518-1526.

2. Hsu, C. T., Huang, G. Y., Chu, H. S., Yu, B., & Yao, D. J. (2011). Experiments and simulations on low-temperature waste heat harvesting system by thermoelectric power generators. Applied Energy, 88(4), 1291-1297.

3. Wang, Yuchao, Chuanshan Dai, and Shixue Wang. "Theoretical analysis of a thermoelectric generator using exhaust gas of vehicles as heat source." Applied Energy 112 (2013): 1171-1180.

4. Nguyen, Nguyen Q., and Kishore V. Pochiraju. "Behavior of thermoelectric generators exposed to transient heat sources." Applied Thermal Engineering 51, no. 1-2 (2013): 1-9.

5. Kim, Shiho. "Analysis and modeling of effective temperature differences and electrical parameters of thermoelectric generators." Applied energy 102 (2013): 1458-1463.

6. Rezania, Alireza. "Integration of Heat Exchangers with Thermoelectric Modules." Thermoelectric Energy Conversion: Basic Concepts and Device Applications (2017)

7. Wojtas, N., L. Rüthemann, W. Glatz, and C. Hierold. "Optimized thermal coupling of micro thermoelectric generators for improved output performance." Renewable energy 60 (2013): 746-753.

8. A.P. Perez-Marín, Mercè Pacios, Álex Morata, and Albert Tarancón. "Silicon-based nanostructures for integrated thermoelectric generators." Journal of Physics D: Applied Physics 51, (2014): 423001.

9. Yilbas, Bekir S., and Ahmet Z. Sahin. "Thermal characteristics of combined thermoelectric generator and refrigeration cycle." Energy conversion and management 83 (2014): 42-47.

10. Jia, Xiaodong, and Yuanwen Gao. "Estimation of thermoelectric and mechanical performances of segmented thermoelectric generators under optimal operating conditions." Applied thermal engineering 73, no. 1 (2014): 335-342.