Waste Heat Recovery of an IC Engine Using Thermoelectric Generator

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Abstract - *The current worldwide trend of increasing transportation is responsible for increasing the use of internal combustion engines. IC engine is the device of high energy usage with low efficiency because maximum amount of energy produced during combustion is lost in the form of heat. As the amount of loss is extremely high, there is a need to control this loss. This paper focuses on the recovery of waste heat from exhaust pipe using a thermoelectric generator. TEG is a device which converts thermal energy directly into electrical energy. An experiment is carried out with four different types of vehicles. Results based on observations and graphs were discussed.*

Key Words: **Thermoelectric generator (TEG), IC engine, Waste heat recovery, Seebeck effect**

1. INTRODUCTION

Thermoelectric generator (TEG) is a device which converts thermal energy (in this case- Heat) directly into electrical energy, using Seebeck effect. TEG reduces the load on alternator thus decrease the fuel consumption. TEG has certain advantages. It is portable, eco-friendly, easy to operate. It is very small, flexible and has no moving parts. It uses nontoxic and non-radioactive materials. Apart from its use in IC engine, TEG is also used to generate electrical energy by burning municipal waste, Industrial waste gas (chimney) and household waste heat.

1.1 Composition of TEG

TEG consists of two ceramic plates called the substrates for n-type and p-type semiconductor thermo elements. These substrates provide mechanical integrity and electrical insulation to these semiconducting elements. The ceramic plates are made up of alumina (Al_2O_3). The semiconductor thermo elements like SiGe, PbTe and their alloys are sandwiched between the ceramic plates. They are thermally parallel and electrical in series to form a thermoelectric module.

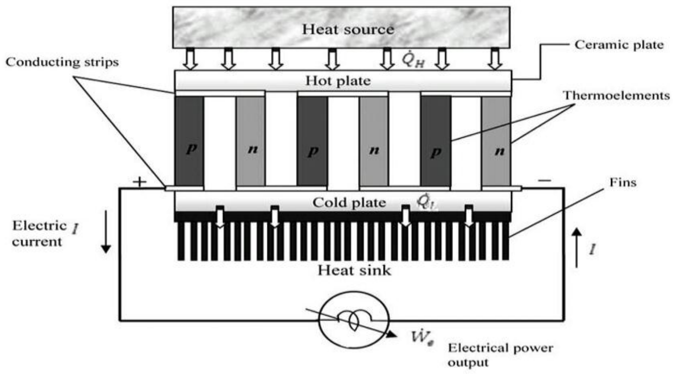

Figure 1- Schematic diagram showing components and arrangement of a typical single-stage TEG

1.2 Working Principle

The working principle of thermoelectric generator (TEG) is mainly based on three theories, namely, Seebeck effect, Thomson effect and Peltier effect.

1.2.1 Seebeck effect-

Seebeck effect is given by Thomas Seebeck, a German Physicist, in 1821. It states that two dissimilar metals when joined at its ends to form a loop, a voltage is developed in the circuit if the two junctions are kept at different temperatures.

1.2.2 Thomson effect-

Thomson effect was given by William Thomson (Lord Kelvin) in 1851. It states that any current carrying conductor (except superconductor), with a temperature difference between two points, will either absorb or emit heat, depending on the material.

1.2.3 Peltier effect-

Peltier effect is given by James Charles Athanase Peltier. It states that when electric current flows between two dissimilar conductors held at a constant temperature, heat is either absorbed or released at the junction depending on the direction of the current flow.

1.3 Working of TEG

If a temperature difference is maintained between the two sides of the thermoelectric couple, thermal energy will move through the device with this heat and an electrical voltage will be generated. This electrical voltage is called the Seebeck voltage.

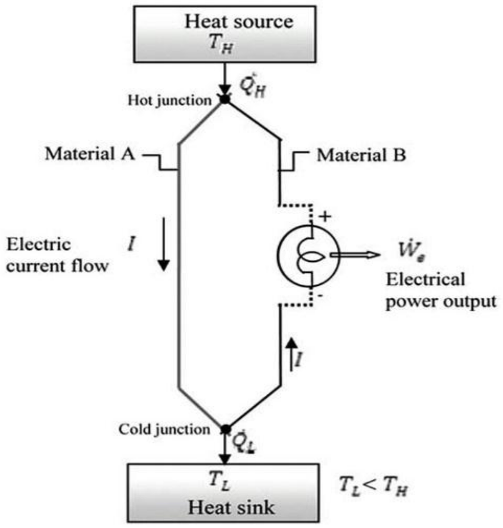

Figure 2- Schematic diagram showing the basic concept of a simple thermoelectric generator (TEG) operating based on Seebeck effect

1.4 Types of TEG

Thermoelectric generator materials and their temperature range is as follows-

Table -1: Types of TEG

Sl. No.	TEG Materials	Temperature range
1.	Materials based on Si-Ge alloys	Higher temperature range upto 1300K
2.	Materials based on alloys of Lead (Pb)	Intermediate temperature upto 850K
3.	Alloys based on Bismuth (Bi) in combination with Antimony (An), Tellurium (Te) or Selenium (Se)	Lower temperature upto 450K

1.5 Figure of merit

The figure of merit Z describes material performance. It depends on the thermoelectric material properties.

$$Z = \frac{\alpha^2 \sigma}{\lambda}$$

where, α = Seebeck coefficient, σ = electrical conductivity, λ = thermal conductivity

2. EXPERIMENTATION

2.1 Materials used in experimentation-

1. Thermoelectric generator-

Model number: TEC1-12706

Size: 40mmX40mmX4mm

Raw material: bismuth telluride

2. Heat source and heat sink-

Heat source-

In this paper, four types of different two wheelers were used for the experiment, so their exhaust pipe acts as a heat source.

Heat sink- Aluminium fin

3. Load-

a. LED indicator

b. USB mobile charging port

4. Digital thermometer-

Two digital thermometers are used to measure the temperature of the heat source and heat sink.

5. Multimeter-

A multimeter is used to measure the generated voltage.

6. Fan-

A fan is used to provide cooling in the heat sink. When the setup is properly attached to a vehicle, it will take atmospheric air at the heat sink.

2.2 Experimental setup-

The experimental setup is done as given below.

Figure 3- Experimental setup

2.3 Experimentation Process-

As the vehicle started, the engine started to release exhaust. The hot junction gets heated and the cold junction gets cooled from the fan, with Seebeck effect it starts generating the voltage. Digital thermometers were continuously measuring the temperature of both heat source and heat sink. Readings were taken for all four vehicles.

3. OBSERVATION AND RESULT-

3.1 Honda Activa

Engine: 109.2cc

Maximum Power: 8bhp @ 7500 rpm

Maximum Torque: 8.94N-m @ 5500 rpm

(cc= cubic centimeter, bhp= brake horse power, N-m= Newton meter)

Time (in second)	Generated voltage (in volts)	Source temperature (in °c) (t1)	Sink temperature (in °c) (t2)	Temperature difference (in °c) (t1-t2)
10	0.26	39.2	35.4	3.8
20	0.41	41.6	36.7	4.9
30	0.57	47.4	38.1	9.3
40	0.63	54.2	42.3	11.9
50	0.69	57.5	45.2	12.3
60	0.75	64.2	49.1	15.1
70	0.86	67.3	50.8	16.5
80	0.98	71.9	52	19.9
90	1.14	75.8	54.3	21.5
100	1.28	81.2	57.9	23.3

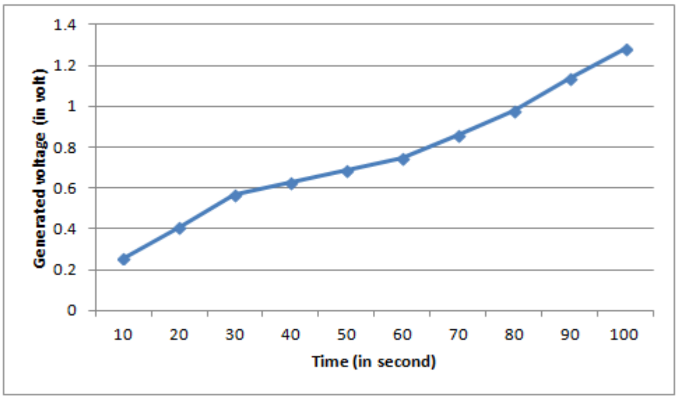

Chart 1(a): Generated voltage vs. time graph

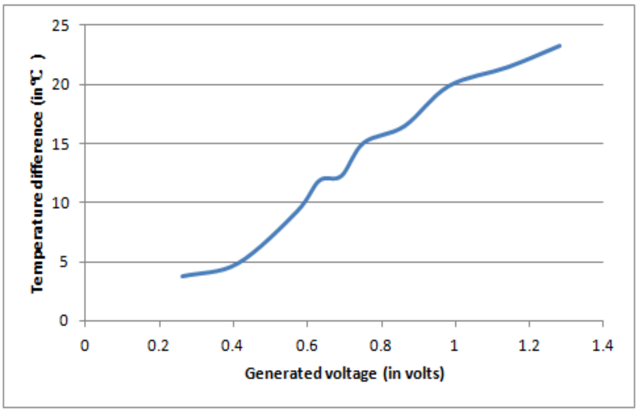

Chart 1 (b): Generated voltage vs. temperature difference

3.2 Hero Pleasure

Engine: 102cc

Maximum Power: 69bhp @ 7000 rpm

Maximum Torque: 8.1N-m @ 5000 rpm

Time (in second)	Generated voltage (in volts)	Source temperature (in °c) (t1)	Sink temperature (in °c) (t2)	Temperature difference (in °c) (t1-t2)
10	0.16	38.2	34.3	4
20	0.23	40.2	36.1	4.1
30	0.35	45.9	39.9	6
40	0.41	53.1	42.2	10.9
50	0.48	56.6	44.6	12
60	0.59	63.8	51.5	12.3
70	0.58	65.1	53.8	11.3
80	0.56	69.3	58.1	11.2
90	0.86	73.9	60.2	13.7
100	0.94	79.2	63.9	15.3

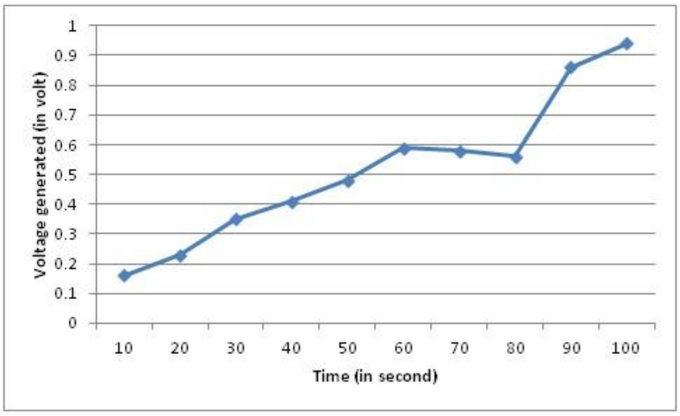

Chart 2(a): Generated voltage vs. time graph

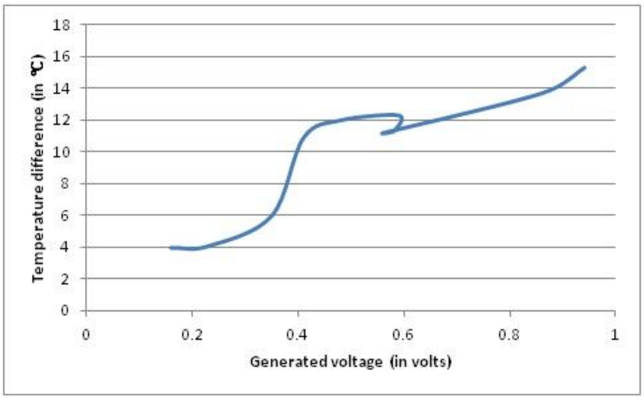

Chart 2(b): Generated voltage vs. temperature difference

3.3 Bajaj Discover

Engine: 124.5cc

Maximum Power: 10.84 @ 7500 rpm

Maximum Torque: 11 N-m @ 5500 rpm

Time (in second)	Generated voltage (in volts)	Source temperature (in °c) (t1)	Sink temperature (in °c) (t2)	Temperature difference (in °c) (t1-t2)
10	0.24	39.4	35.2	4.2
20	0.43	42.1	37.3	4.8
30	0.56	48.3	40.2	8.1
40	0.67	53.8	43.4	10.4
50	0.71	58.1	46.9	11.2
60	0.75	65.7	53.7	12
70	0.86	68.4	56.2	12.2
80	0.99	72.3	59.3	13
90	1.21	75.9	61.1	14.8
100	1.36	82	63.4	18.6

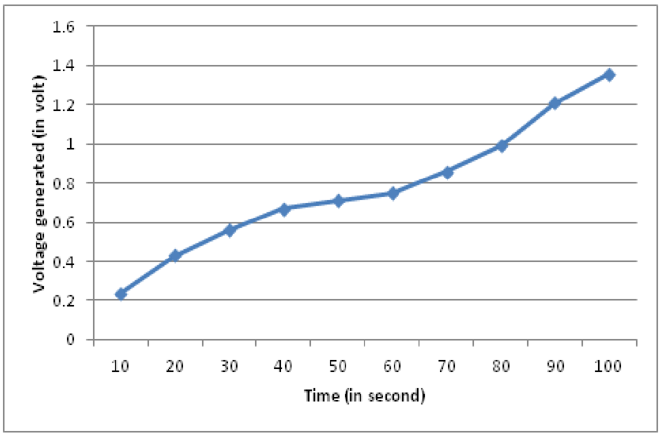

Chart 3(a): Generated voltage vs. time graph

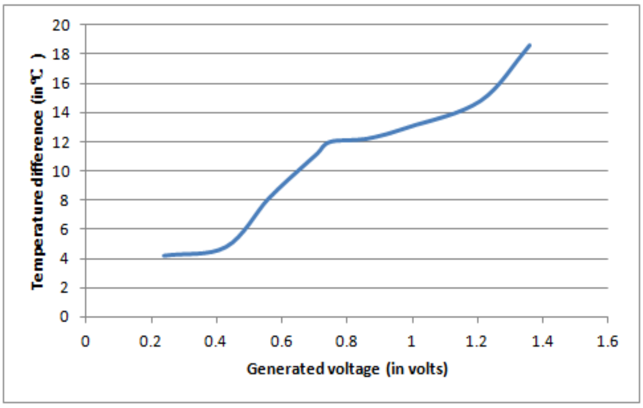

Chart 3(b): Generated voltage vs. temperature difference

3.4 Bajaj Pulsar

Engine: 134.6cc

Maximum Power: 13.37 @ 9000 rpm

Maximum Torque: 11.4 N-m @ 7500 rpm

Time (in second)	Generated voltage (in volts)	Source temperature (in °c) (t1)	Sink temperature (in °c) (t2)	Temperature difference (in °c) (t1-t2)
10	0.26	39.3	36.1	3.2
20	0.44	42.2	37.4	4.8
30	0.53	47.1	41.4	5.7
40	0.69	52.9	43.9	9
50	0.76	57.3	46.7	10.6
60	0.8	64.8	51.2	13.8
70	0.89	69.3	54.8	14.5
80	1.20	74.1	59.6	14.5
90	1.44	77.8	62.4	15.4
100	1.69	83	65.2	17.8

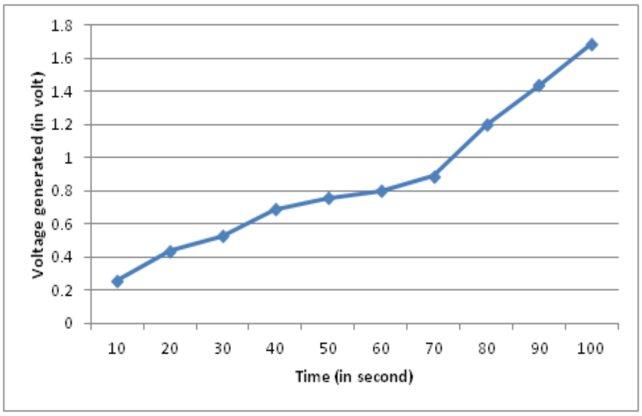

Chart 4(a): Generated voltage vs. time graph

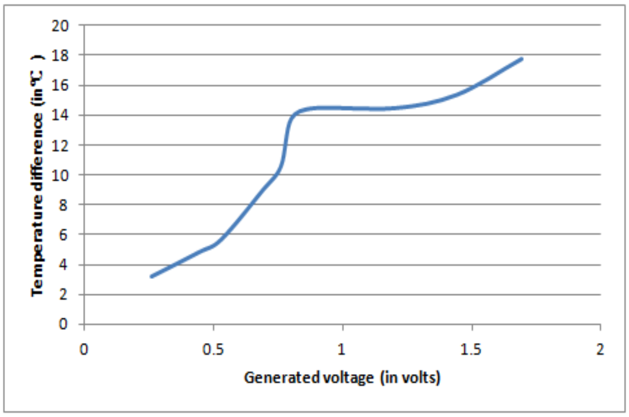

Chart 4(b): Generated voltage vs. temperature difference

3. CONCLUSION

1. From the above observation, it clear that generated voltage is directly proportional to temperature difference and time.

2. Initially voltage is generated at the slower rate. After some time, it increases rapidly.

3. It doesn't affect the engine performance of the vehicle.

4. It will store the generated electrical energy in batteries, hence reducing the load of the alternator.

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