International Journal of Advanced Mechanical Engineering.
ISSN 2250-3234 Volume 7, Number 1 (2017), pp. 1-14

http://www.ripublication.com

Design and Fabrication of Silencer Waste Heat Power Generation System Using Thermo-Electric Generator

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Abstract

The current worldwide trend of increasing transportation is responsible for increasing the use of internal combustion engines. I.C engines, the devices with a high energy usage and low efficiency because roughly 75 % of the energy produced during combustion is lost in the exhaust and in the coolant of the engine in the form of heat. As a huge amount of energy is lost, there is urgent need to design a advice to trap this loss.This paper proposes and implements a waste heat recovery system using a thermoelectric generator (TEG) designed for four stroke I.C. engine. The system converts the waste heat from the exhaust manifold into electrical energy using a TEG. The output is then boosted by a Joule Thief converter to run the required load or to charge a battery. The experimental results demonstrate that the proposed system recovers considerable amount of waste heat which can be used to power some auxiliary automobile devices.

Keywords: IC engine, Heat energy recovery, Silencer bend pipe, TEG, Electric load.

1. INTRODUCTION

The automobile industry is one of the world's most important economic sectors. Automobiles use IC engines, which have huge amount of energy loss up to 70% in the form of heat. In the recent times, scientists have tried and refined the automobile technology appreciably, but could not control the loss in IC engine in the form of waste heat. This paper focuses its attention not to control the waste heat in IC engine, rather it focuses on trapping the waste heat to generate electricity by using a suitable device called thermoelectric generator (TEG).

Thermoelectric generator (TEG) is a device which converts thermal energy directly into electrical energy, using seebeck effect. The use of TEG in automobile IC engine is a revolutionary idea, which reduce load on alternator which changes the battery, thus contributing to decreases in fuel consumption.

The temperature of the 'exhaust bend pipe surface' through which exhaust gases are flowing, ranges between 200 °C to 300°C,by attaching a copper plate to this bend pipe hot junction of the thermoelectric module is made, other cold junction is created by aluminum heat sink, discussed in detail in the paper. As this potential difference is created, voltage is produced using seebeck effect. The produced voltage is further amplified by using booster circuit and is tested across the load. Tzer-Ming Jeng et. al. (2016) [1] have carried out a study on Design, Manufacture and Performance Test of the Thermoelectric Generator System for Waste Heat Recovery of Engine Exhaust. The study successfully investigated the effects of the engine rotation speed and the mean velocity of external cooling air on the temperature and discharged quantity of engine exhaust gas. Experiments were also performed to measure the relationship between the external load resistance and the TEG output voltage/current, as well as between TEG output voltage and generated power/efficiency. A correlation was derived for calculating the maximum generation power of a single-chip TEG and the temperature difference between the hot and cold faces of TEG. Z.B. Tang et. al. (2015) [2] have studied a research on thermoelectric generator's electrical performance under temperature mismatch conditions for automotive waste heat recovery system. They concluded that a proper mechanical pressure applied on the module improves the electrical performance. The experimental results showed that the power loss of the modules in series connection is significant, 11% less than the theoretical maximum power, due to the temperature mismatch condition. This situation is improved with thermal insulation on the modules and the power loss due to the inconsistent temperature distributions reduces to 2.3% at the same working condition. Anchal Dewangan et al (2015) [3] have carried out an Experimental analysis of Waste heat recovery using TEG for an internal combustion engine. It was found that maximum amount of heat carried away by hot exhaust gases are obtained at speed of 1300 RPM and load of 20 Kg and the value is 2597.61 J/s. When TEG is sandwiched between hot junction and cold junction and speed of engine is maintained at 1300 RPM with load of 20 kg and cold water flows at a temperature of 16 °C, maximum power obtained from TEG module is 29.94 J/s. Aravind Karuppaiah C. et. al. (2014) [4] have carried out a study on Fabrication and Analysis of Thermo Electric Generator For Power Generation. They used Silicon and Germanium as TEG material and found that TEG system of charging the battery could reduce the fuel consumption and also battery life used in automobiles could be increased. T Stephen John (2014) [5] has studied High Efficient Seebeck Thermoelectric Device for Power System Design and Efficiency Calculation. A Review of Potential House holds Appliances. Here Bismuth telluride material is used and found that the thermoelectric power generated was more than 2.5 watt DC per TEG, which is economically attractive. R. Saidur et. al. (2012) [7] have studied on Technologies to recover exhaust heat from internal combustion engines. The study also identified the potentials of the technologies when incorporated with other devices to maximize potential energy efficiency of the vehicles. It should be noted that TEG technology can be incorporated with other technologies such as PV, turbocharger or even Rankine bottoming cycle technique to maximize energy efficiency, reduce fuel consumption and green house gas (GHG) emissions.

1.1.Working of TEG:
The EMF cause by temperature gradient across the junctions of two dissimilar conductors, which form a close loop is seebeck effect shown in figure 1.

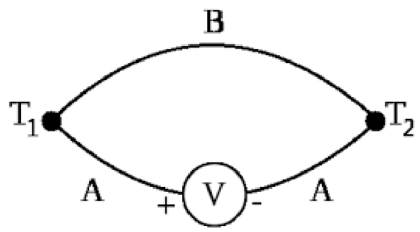

Figure 1: Seebeck effect [11]

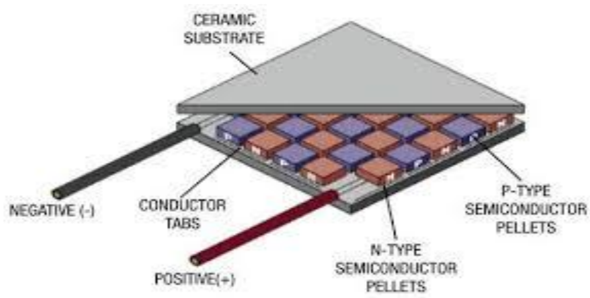

Figure 2: Thermoelectric generator [4]

A single thermoelectric couple is constructed from two ‘pellets’ of semiconductor material usually made from Bismuth Telluride (Bi2Te3). One of these pellets is doped with acceptor impurity to create a P-type pellet; the other is doped with donor impurity to produce an N-type pellet. The two pellets are physically linked together on one side, usually with a small strip of copper, and mounted between two ceramic outer plates that provide electrical isolation and structural integrity. For thermoelectric power generation semiconductor material A and B joint together show in figure.1, if a temperature difference is maintained between two sides of the thermoelectric couple (T1 and T2), thermal energy will move through the device with this heat and an electrical voltage, called the Seebeck voltage, will be created. If a resistive load is connected across the thermoelectric couple’s output terminals, electrical current will flow in the load and a voltage (V) will be generated at the load. Practical thermoelectric modules are constructed with several of these thermoelectric couples connected electrically in series and thermally in parallel.

1.2. Types of TEG:

Thermoelectric generator materials and there temperatures range is as follows [3].There are number of materials known till date but few are identified as thermoelectric materials.

Table 1: Types of TEG

Sr no.	TEG Materials	Temperature range
01	Material based on Si-Ge alloys	Higher temperature upto1300K
02	Materials based on alloys of Lead (Pb)	Intermediate temperature up to 850K
03	Alloys based on Bismuth (Bi) in combinations with Antimony(An), Tellurium (Te) or Selenium (Se)	Low temperature up to 450K

Effective thermoelectric material should have a low thermal conductivity but high electrical conductivity. The thermo electric material used in the present work is Bismuth telluride. The material is selected on the basis of power factor, figure of merit and melting point. The performance of thermoelectric materials can be expressed as.

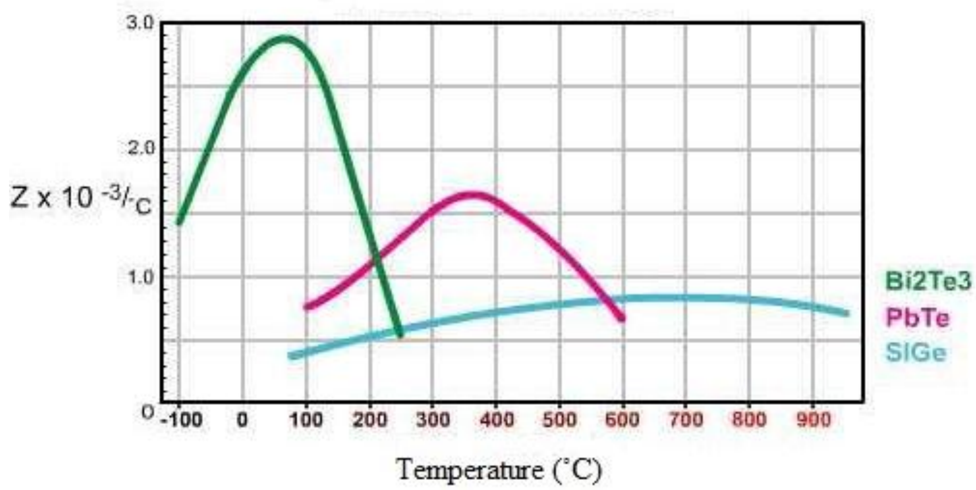

Figure 3: Performance of Thermoelectric Materials at various temperatures [4]

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

$$z = \frac{\alpha^2 \sigma}{\kappa}$$

where, α =Seebeck coefficient, σ = electrical conductivity, k = thermal conductivity.

Single pair of thermoelectric couple contains one p and n type of semiconductor legs and a module has number of couples electrically connected in series and thermally in parallel. The enclosed parallel plates are made up from ceramic substrate which is electrical insulators.

2. MATERIALS AND EQUIPMENTS USED IN THE EXPERIMENTATION

(i) Thermoelectric generator:

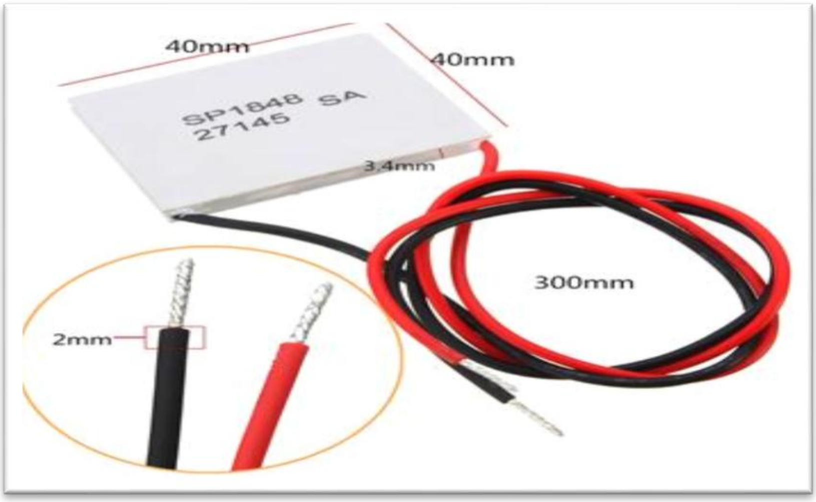

Figure 4. Thermoelectric generator

A thermoelectric generator is a semiconductor based electronic component that converts heat into electricity using a phenomenon called Seebeck effect. Two thermoelectric generators connected in series are used in the experimental setup.
The thermoelectric module of bismuth telluride having hot side operating temperature is up to150°C.the power output of TEG module is 3.2 watt at temperature difference 100°C.
There are two TEG connected thermally in parallel and electrically in series so increasing voltage.

1. Model : SP1848-27145
2. Operating Temperature : -40 to 150°C
3. Cable Length: 20cm (approx).
4. Principle: Seebeck effect.
5. Raw material: bismuth telluride.
6. Size : 40mmx40mmx3.4mm
7. Merit (Z): 2.5 ~ 3.0 × 10-3W / ℃

Bismuth telluride based module is easily available at a low cost with different power and size so this module is used in present work.

(ii) Heat source and heat sink:

- A heat source is an object that produces or radiates heat.
    1) Copper heat source

Figure 5. Copper heat source fabricate for the present study

Copper has the high thermal conductivity and melting point easy to weld at silencer bend pipe which transmit heat to the thermoelectric generator. Therefore in this experimental setup, copper plate as a heat source at hot side is used. The hot junctions of the TEGs are connected to the copper plate needed to the bend pipe of I.C. engine carrying the hot exhaust gases. This copper plate have a smooth surface and dimensions 185mm x75mm x6mm acts as a heat source.

- A heat sink is an object that absorbs and dissipates heat from another object using thermal contact.

2) Aluminum heat sink

Figure 6. Aluminum heat sink fabricated for the present study

The flat back type aluminum heat sink is used in the present investigation. It contains number of fins cooled by air cooling system. The temperature of aluminum heat sink (cold side) is the room temperature (around 26 to 30°C). The aluminum heat sinks fins 25 in numbers and spread over 70mm x80mm area with 0.5mm thickness which is shown in fig.6.Twoheat sinks are used in the experimental setup. Aluminum heat sink is used because it has high thermal conductivity it is easily available, low cost, light weight and flat back side is properly attached with TEG.

(iii) Booster circuit:

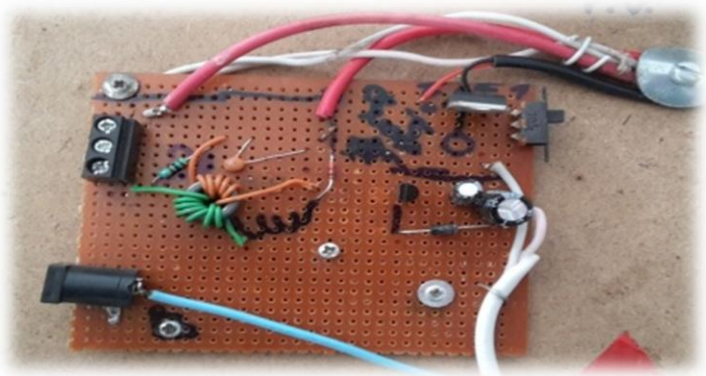

Figure 7: Joule Thief Converter (Booster circuit) used in present study

Boost converter is used for increase the input voltage obtained from TEG. The EMF produced from TEG may be not enough to operate the load. There are number of types of voltage booster circuits. In this work simple Joule Thief circuit with round ferrite toroid, resistance (1K) and NPN transistor is used. This circuit is used for DC to DC voltage booster but its efficiency is 70% to 80%.Voltage booster circuit is used for boosting the voltage of low power TEG [6]. In this work voltage boosted by booster circuit is displayed using digital multimeter, as shown in figure7.

(iv) Multimeters:

Continuous monitoring of the system performance is necessary part of the experiment, in this respect three multimeters are connected across the circuit at three different positions. One is connected after TEG module to monitor its output voltage. The second is connected after booster circuit to monitor booster voltage and the third one is connected across the load to monitor current flowing through the circuit. The DT830D digital type multimeter having dc voltage range 200 V having an accuracy ± 0.5% and dc current range 200 MA- 10 A, having accuracy ± 1.2% and ± 2.0% respectively are used in the experimentation.

(v) Digital Thermometer:

This experimental setup has two digital thermometers, they measure the temperature of (hot junction) copper plate and (cold junction) aluminum heat sink. The range of hot side digital thermometer is -50˚c to 200˚c and cold side digital thermometer range is -50˚c to 99˚c both thermometers have contact type probe.

(vi) Heat paste:

Heat paste is a viscous fluid substance with properties similar to grease. It increases the thermal conductivity of the thermal interface by filling the micro air-gaps present due to the imperfectly flat or smooth surfaces. The heat paste is applied to the both the junctions of the TEG in order to have smooth heat transfer. It is thermally conductive but usually electrically insulating. In this setup silicon based white colored compound is used which can withstand temperature up to150 ˚C.

(vii) I.C. Engine:

The I C engine used in the system has the following specifications: shown in figure 10.

Table 2. I C engine specifications.

Sr no	Engine Displacement	92.20 cc
1	Engine type	4-stroke, Single Cylinder, Air-Cooled engine
2	Engine starting	Kick Start
3	Maximum power	7.00 bhp@8000 rpm
4	Maximum torque	0.73 @ 5000 rpm

2.7 Load:

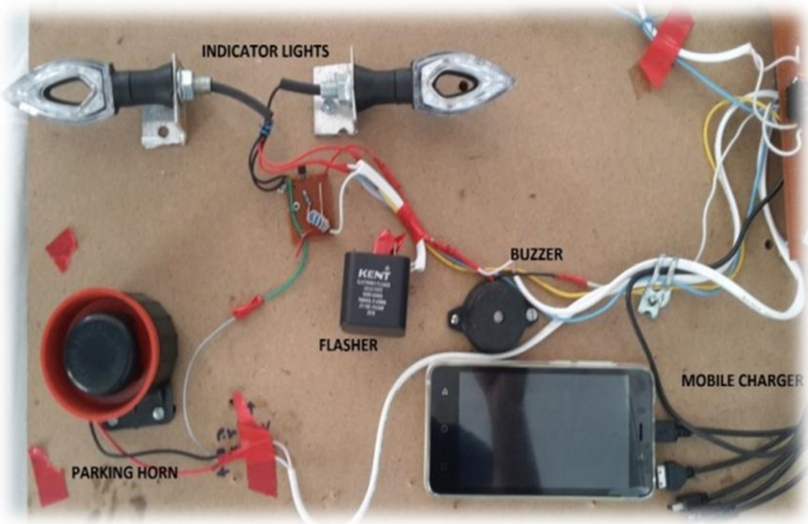

Figure 8: Load attached across TEG in the present study

The load attached across the circuit have-
(a) LED Indicator
(b) Electronic Flasher
(c) Piezoelectric Buzzer
(d)Mobile charger
(e) Parking Horn

(a) LED Indicator:

Turn signal indicator LED universal lamp last upto 100 times longer than incandescent bulb. Turn on significantly faster than standard factory bulbs, It is energy efficient, long life, eco-friendly, design flexibility, light weight. The lamps have 20 LED bulbs in each, short stalk and classic black look.

Specifications:-
Colour:-blue
LED in each light-20
Operating voltage-9 to 12 V
Power consumption - 1 to 1.5 W
Lens-5.1(L)*2.9(W)*1.3(H) cm shown figure 8.

(b) Electronic Flasher:

The turn signal flasher is a device installed in a vehicle lighting system with the primary function of causing the turn signal lamps to flash when the turn signal switch is activated to left or right. Electronic flasher is generally used for LED indicator having very low power consumption. Electronic flasher last more than electro-mechanical flasher and thermal flasher. Low power consumption, light weight, small size, long life, no noise and sensitive.
Specification:-
KENT electronic flasher (2 pin)
Voltage 9 V to 12 V
Operates from 0.05 A to 7 A
Temperature range -40 ˚C to 85˚C

c) Piezoelectric Buzzer:

It is an electronic device commonly used to produce sound. It is light weight, simple construction and low price. Shown in figure 8.
Specifications:
Operating Voltage- 6 to 12 V
Current- 20mA @ 12 V
Decible-70
Tone – continuous

d) Mobile charger:

Specifications:
It is L7805 voltage regulator (Output 5 V)
It contains 5 charging point.
Power consumptions 1 to 2 W

e) Electronic Horn:

Electronic horn consumes less power than conventional horn.
Specifications:
Operated at Voltage -12 V
Operating current- 0.15 A
Decible-85
Fixing- bolt
The entire load is mounted on plywood panel as shown in figure 8.

3. EXPERIMENTATION

3.1 Experimental setup:

Figure 9: TEG Setup fabricated for present study

To the bend exhaust pipe of the IC engine specified above, a copper plate 6 mm thick is welded to form the junction of the thermo electric generator. Two thermoelectric generators connected in series, are placed on the hot copper plate acting hot junction, on the other side of the TEG, the cold sink of aluminum is connected as shown in fig.10. In between hot and cold junction TEG's are fitted by nuts and bolts shown in figure 9.The hot and cold side temperature of TEG is continuously monitored using digital thermometers. The heat paste is applied at the junction to ensure proper contact between surfaces and conduction of heat.

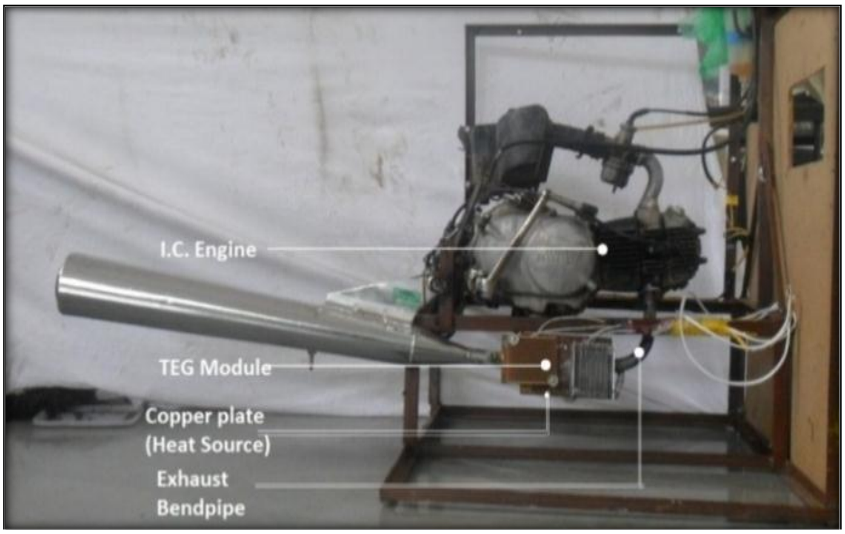

Figure 10: Experimental setup of present study

3.2 Experimentation:

As he engine starts, the hot junction gets heated
and the heat transfer rate increases across the thermoelectric generator, now with Seebeck effect it starts generating voltage. The voltage generated will be of very small magnitude hence the Joule Thief voltage booster shown in fig 7. is used to boost up the voltage. Two digital multimeters are attached to continuously monitor the generated and boosted voltage. This boosted voltage is connected across the load and tests are done. One important thing which is worth mentioning is, if this system is attached to a vehicle, when the vehicle move the air flowing over the fins of Aluminum sink will be fast creating more cooling of the sink, hence maintaining more temperature difference across the TEG and more voltage generation. Readings were taken by running the engine at different RPMs, recorded in table 3.

4. EXPERIMENTAL RESULTS

The designed system is made to run at three different Speeds and the results are as follows:

Table 3: Results

Speed Rpm	Time (Sec)	Sink temp (t1) ˚c	Source temp (t2) ˚c	Temp (t2-t1) ˚c	Generated voltage (V)	Boosted Voltage
2000	172	31.4	54.9	23.5	02.01	3.62
	329	35.8	87.5	51.7	04.02	7.55
	340	36.1	89.1	53	6.04	14.12
	363	36.9	92.5	55.6	08.02	15.23
	485	37.2	104.1	66.9	10.10	19.14
	558	39.9	118.2	78.3	12.00	22.05
4000	115	31.5	58.9	27.4	02.00	03.65
	225	36.7	82.8	46.1	04.02	07.53
	248	37.4	97.2	58.1	06.02	14.02
	265	35.4	102.1	66.7	08.00	15.15
	299	40.9	109.0	68.1	10.01	19.04
	357	44.7	127.9	83.2	12.00	22.08
6000	007	30.7	57.9	27.2	02.00	03.16
	098	32.5	88.3	55.8	04.40	07.37
	104	35.7	90.9	55.2	06.00	11.71
	113	36.2	94.1	57.9	08.01	16.02
	124	36.8	98.5	61.7	10.01	20.52
	146	39.2	106.5	67.3	11.80	21.22

(All voltages are unloading conditions)

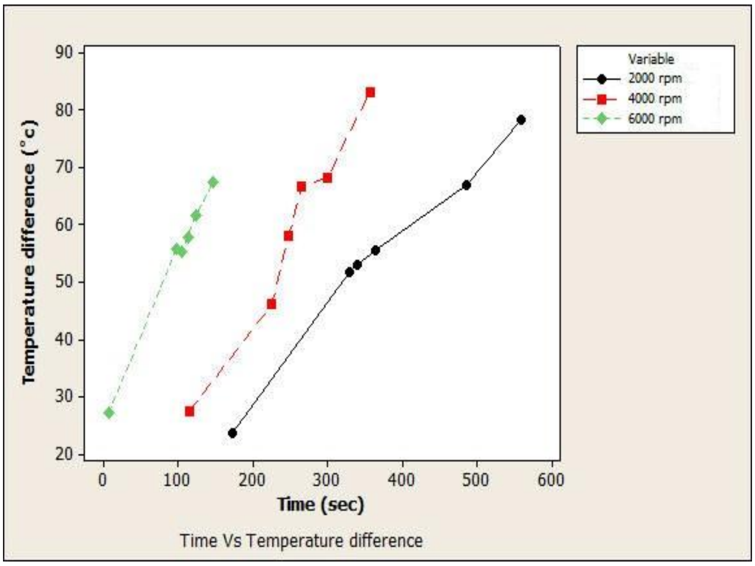

Figure 11: Shows that time is directly proportional to temperature difference.

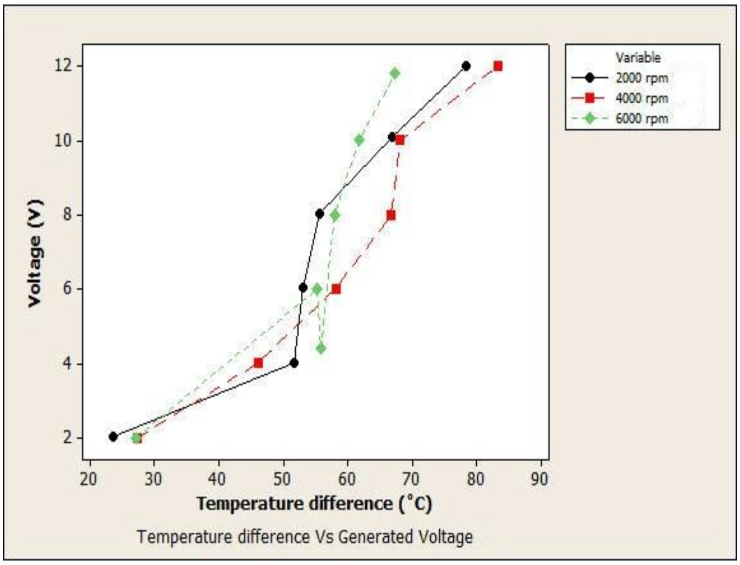

Figure 12: Shows that temperature difference is directly proportional to voltage

5. DISCUSSION

The TEG used in the present experiment is operated between the temperature range 40˚C to 150˚C as the engine run, the silencer temperature reach 150˚C. When the engine operated at 2000rpm then the heat source attached on the surface gets heated up to 118.2˚C in 9.3 minute and voltage generated is 12 volts. Similarly when engine runs at 4000rpm heat source get heated up to 127˚C in 5.95 minute generate voltage is 12 volts. When engine run at 6000rpm heat source is heated up to 106.3˚C in 2.43 minute and generated 11.80 volts. The experimental setup use only two TEG's which are operated at maximum temperature difference is 83.2˚C. And it is operated at maximum temperature up to 100˚C. Thermocouples are attached on the surface of the silencer pipe, the temperature recorded of silencer pipe is average 130˚C when vehicle is running (on road). If the silencers bend pipe temperature riches more than 150˚C then it will require high temperature TEG (200˚C). The main purpose of joule thief CKT is amplify the voltage generated by TEG as TEG generate less voltage and that voltage is not enough to operate electrical load. The load connected across the system is led indicators, electronic flasher, and electronic horn. Temperature difference vs. voltage graph shows at 6000 rpm engine speed in 146 second gives temperature difference is 67.3˚C and at that point we got 12 volts. And at 6000 rpm engine speed gives much higher temperature difference than 2000rpm and 4000 rpm. Making system more effective.

CONCLUSION

1. This project aims to find a possible way to recover the waste heat from the exhaust of I.C. engine as well as to design and fabricate one such system to serve the aim.
2. Experimentally it is found that when two thermoelectric generators are connected in series. This generated power either directly used to run some auxiliary devices of an automobile or may be stored in the battery and used later.
3. These auxiliary loads can be supplemented from battery to this system thereby reducing load on alternator.
4. The study also investigates the effect of engine speed on temperature difference and voltage generated.
5. The engine performance is unaffected by the designed system because heat extracted from the surface of the bend-pipe of the exhaust manifold which does not affected the working of engine.
6. If higher temperature range is required then TEG module must be changed to higher temperature range (200˚C). Thus, the above stated system may be successfully implemented in different automobile engines, with slight changes.

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