Power Generation by using Exhaust Gas Heat from an Internal Combustion Engine

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***Abstract*— Internal Combustion engines have been utilized for transportation and other needs for a long time. These engines have proven to be an effective source of energy. However, a lot of the energy produced by these engines goes wasted and unutilized. In today's age of fuel crisis, wastage of energy produced through engines cannot be tolerated. This work aims at reclaiming energy going wasted through the silencer of engines. Using devices called Peltier Modules, the heat energy present on the silencer are converted into useful electrical energy.**

Keywords—Peltier Module, Thermoelectric Generator, Waste Heat Recovery.

I. INTRODUCTION

One of the many methods to increase power output with low fuel input is to extract heat energy from the exhaust of engines and utilize it towards reducing the overall fuel consumption in the engine. This is made possible by considering the fact that only 30 to 40% of total energy produced in an engine is utilized to run the vehicle and engine accessories. The rest is wasted in the form of exhaust heat and noise. Heat present in the exhaust gases which otherwise serves no purpose can be extracted and used to run various energy consuming devices in an automobile, thereby reducing the total dependence on combustion for energy. The usage of devices called Thermoelectric generators (Peltier Modules) to convert the heat energy of the silencer to electrical energy is a promising method of generating electricity.

Thermoelectric Generator (Peltier Module)

Thermoelectric generator, more commonly known as a Peltier Module, is a solid-state device. It consists of arrays of P and N type semiconductor materials. P and N type materials are joined thermally in parallel and electrically in series. Thermoelectric generator consists of number of alternate P and N type semiconductor elements connected in series with metallic connectors and sandwiched between ceramic plates forming module of the thermoelectric generator. The ceramic plates are electrically insulating and thermally conductive. When a temperature difference is maintained across the module, electrical power will be generated.

Power generation on automobiles through various means has been a highly researched topic in science. Many researchers have tried to find methods to extract most of the energy produced by the engine without allowing any wastage of power. Dynamos are fitted onto the engine shaft to allow for the running of vehicle electronics. Along the same lines, researchers have implemented the method discussed in this work. The inferences of those papers have been discussed below.

P Mohammed Shameer et al. [1] studied that electrical energy can be produced from exhaust gases by using a thermoelectric generator; commonly known as Peltier module; that works on the principle of see back effect. They utilized a Peltier Module made of Bismuth Telluride (Bi_2Te_3), booster circuit and battery to achieve it. After carrying out the experiments they found that the voltage produced at the output is directly proportional to the temperature difference across the Peltier Module.

J S Jadhao et al. [2] found that heat energy from the exhaust gases can be utilized to produce electrical energy using the Peltier Module. They made use of a catalytic converter, heat exchanger, Peltier Module and a power converter to achieve it. They also tried different methods like piezoelectric generation and thermionic generation to produce electricity.

Basel I Ismail et al. [3] found that the electrical energy can be generated from exhaust gases using a Peltier Module. They analyzed the efficiencies and usability of various materials like Bi_2Te_3, PbTe, $FeSi_2$ and many other materials of being used in Peltier Modules and found that for automobile applications, the most suitable Peltier Module material would be PbTe.

D S Deshmukh et al. [4] have found that the performance of Peltier Module used to generate electrical energy can be improved by using water source as cooling media than the air source as per experimentation study. This eco-friendly power generation method can be implemented for domestic and commercial use at an affordable cost. Further study can be extended by increasing the number of Peltier Modules in series and parallel.

Referring the above literature, it was found that it would be suitable to generate a sufficient electrical power using Peltier Modules. The heat dissipated from exhaust of an IC engine can be extracted for future usage using Peltier modules. This helps in extracting a large portion of energy that goes wasted in an engine through its exhaust.

II. METHODOLOGY

After performing the research to select the most effective and efficient ways to extract energy from the engine exhaust of the vehicle, the following components were required to implement the same.

2.1 Four Stroke Petrol Engine

A 4 Stoke Petrol Engine of Suzuki Heat 125 is being used for the purpose of this analysis. The specifications of the engine are given below.

Engine specifications

- Model of the vehicle used : Suzuki Heat
- Displacement : 124cc
- Maximum power : 8.83Bhp @ 7000rpm
- Maximum torque : 10Nm @ 3500rpm
- Number of cylinders : 1
- Cylinder bore : 53.5mm
- Stroke : 55.2mm

The 4-stroke petrol engine also known as the Otto cycle engine requires 4 different strokes to complete one cycle. These engines make use of spark plug for the ignition of the fuel. Each Otto cycle consists of an adiabatic compression, addition of heat at constant volume, an adiabatic expansion and release of heat at constant volume.

2.2 Thermoelectric generator (Peltier Module)

Thermoelectric generator; commonly known as a Peltier Module; produces electric current from heat and is a solid-state device. It contains no moving parts and are completely silent unlike traditional dynamic heat engines. It can be easily operated with small heat sources and small differences in temperature. Due to great amount of waste heat emitted by internal combustion engine operation, there is a huge scope for producing electricity by utilizing the heat from a vehicle silencer. The Peltier module being used for the purpose of this work is TEC1-12706. It is composed of Lead Tin (PbSn). It has a maximum value of temperature difference possible at 70^0C. The specifications of the Peltier module are shown in the below Table 2.1.

Table 2.1: TEC1-12706 Specifications

T_h (ºC)	27	50	Hot side temperature at environment
DT_{max} (ºC)	70	79	Temperature difference between cold and hot side of the module
U_{max} (Volts)	16.0	17.2	Voltage applied to the module at DT_{max}
I_{max} (Amps)	6.1	6.1	DC Current through the module at DT_{max}
Qc_{max} (Watts)	61.4	66.7	Cooling capacity at cold side of the module at DT=0 ºC

2.3 Non-Contact Thermometer

An infrared thermometer is a thermometer which infers temperature from a portion of the thermal radiation sometimes called black-body radiation emitted by the object being measured. They are sometimes called laser thermometers as a laser is used to help aim the thermometer, or non-contact thermometers or temperature guns, to describe the device's ability to measure temperature from a distance. By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can often be determined within a certain range of its actual temperature. Infrared thermometers are a subset of devices known as "thermal radiation thermometers". The non-contact thermometer used in this work was HTC MT4. The specifications of the same are listed in Table 2.2.

Table 2.2: HTC MT4 Specifications

Temperature Range	-50^0C to 550^0C
Accuracy	± 2%
Response Time	< 500 ms
Resolution	0.1^0C

2.4 Multimeter

A multimeter or a multitester, also known as a VOM (Volt-Ohm-Milliammeter), is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter can measure voltage, current and resistance. Analog multimeters use a microammeter with a moving pointer to display readings. Digital multimeters (DMM) have a numeric display, and may also show a graphical bar representing the measured value. Digital multimeters are now far more common due to their cost and precision, but analog multimeters are still preferable in some cases, for example when monitoring a rapidly varying value. The multimeter used in this work was DT-9205A.

2.5 Heat Sink

A heat sink is a passive heat exchanger that transfers heat generated by an electronic or a mechanical device to a fluid medium, where it is dissipated away from the device, thereby allowing regulation of the device's temperature at optimum levels. They are used in order to increase the surface area and in turn increase the rate of heat transfer from the device to the surroundings.

2.6 Thermal Paste

Thermal paste is a thermally conductive but electrically insulating compound which is commonly used as an interface between heat sinks and heat sources. The main purpose of thermal paste is to eliminate air gaps or spaces which may increase insulation from the interface area in order to maximize heat transfer.

Procedure

In order to check the temperature over the circumference of the silencer, a non-contact thermometer was selected. Using the non-contact thermometer, the temperature of the silencer over an interval of 2 inches when the engine was throttled to its maximum capability was measured. Another trial was performed after the vehicle was allowed to be turned on for 5 minutes and then the temperatures at the salient points were noted. These two measurements were termed as Trial 1 and Trial 2 and the measurements are shown in Table 2.3. By performing this analysis, the most suitable region on the silencer for the installation of the Peltier modules was selected.

Table 2.3: Silencer Surface Temperature

Sl. No.	Distance from the Silencer Opening in Inches	Temperature in ^{0}C (Trial 1)	Temperature in ^{0}C (Trial 2)
1	2	30	48
2	4	30.2	47.9
3	6	30.5	51
4	8	31.6	55.2
5	10	32.3	58.6
6	12	34.5	62.6
7	14	35.5	67.9
8	16	41.2	77.7
9	18	43.2	82.4
10	20	41.4	80.4
11	22	42.4	80.8
12	24	46.1	127.3
13	26	43.7	135.9
14	28	54.5	146
15	30	67.6	135
16	32	62	126.9
17	34	78	95
18	36	96	120
19	38	125	170.8
20	39 (Bend 1)	43	163.4
21	40	134	179
22	42	156	190.5
23	44	179	199.5
24	46	174	200
25	47 (Bend 2)	207	191

From the above tabulation, it is evident that the vertical stretches of silencer at the front of the vehicle between bend 1 and bend 2 yielded the most desirable temperatures. Also, this region would be the most effectively cooled through air cooling.

It was to be analyzed if the power output of a Peltier module would increase if more than one of them were connected to each other in either series or parallel when compared to the output of a single Peltier module. To do the analysis, a single Peltier module was initially mounted onto the heat sink. The heat sink would act as an air-cooling system when the vehicle would be in motion. This setup was mounted onto the silencer at the site selected through the previous analysis. A round brass gasket was used to clamp the setup into place and a smaller gasket was fitted onto the bottom of the setup to prevent slippage during motion. A multimeter was used to measure the output voltage of the Peltier module. The setup prepared has been shown in the Fig. 2.1 and Fig. 2.2.

The analysis was performed by maintaining the initial silencer temperature at 100^{0}C as a reference for all trials. The output of the setup was measured for a succession of every 5 kmph increase. The experiment was repeated under the same conditions for both series and parallel configurations. The tests were performed at a straight stretch of road to ensure invariability of readings due to road conditions and to prevent speed decrease during trials. The readings obtained during this analysis have been tabulated in the results section.

Fig. 2.1. Vehicle with Peltier module setup mounted onto the silencer

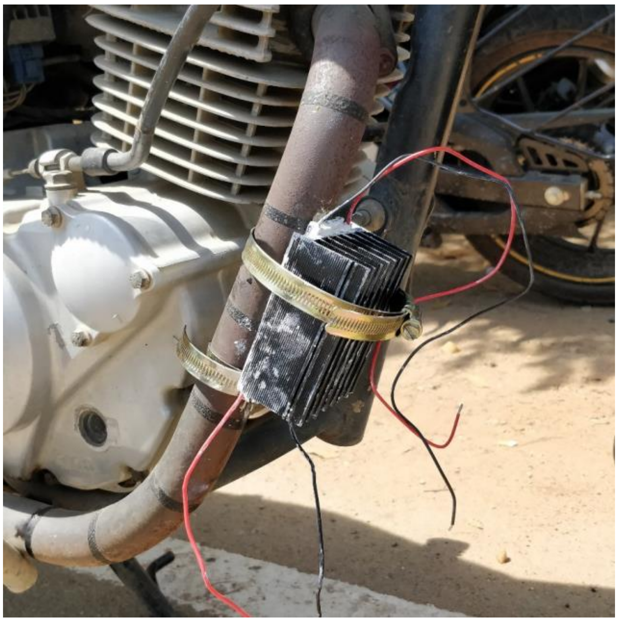
Fig. 2.2. Close up view of Peltier module setup mounted onto the silencer

III. RESULTS

The results of the analysis performed on the Peltier modules mounted onto the vehicle for a single, two in series and two in parallel configurations are given in Tables 3.1, 3.2 and 3.3 respectively.

Table 3.1: Power vs Speed of Vehicle with Single Peltier Module

Sl. No.	Speed in Kmph	Voltage in Volts	Current in Amps	Power in Watts
1	0	0.52	0.108	0.0563
2	5±1	0.54	0.113	0.061
3	10±1	0.56	0.116	0.065
4	15±1	0.59	0.123	0.072
5	20±1	0.61	0.127	0.077
6	25±1	0.63	0.131	0.083
7	30±1	0.65	0.135	0.088
8	35±1	0.68	0.142	0.096
9	40±1	0.7	0.146	0.102
10	45±1	0.72	0.15	0.108
11	50±1	0.76	0.158	0.120
12	55±1	0.99	0.206	0.204
13	60±1	1.1	0.229	0.252

From the above table, it can be seen that the maximum power obtained from a single Peltier module was about 0.25W.

Table 3.2: Power vs Speed of Vehicle with Peltier Modules in Series

Sl. No.	Speed in Kmph	Voltage in Volts	Current in Amps	Power in Watts
1	0	1.67	0.348	0.581
2	5±1	1.69	0.352	0.595
3	10±1	1.8	0.375	0.675
4	15±1	1.84	0.383	0.705
5	20±1	1.88	0.392	0.736
6	25±1	1.94	0.404	0.784
7	30±1	2	0.416	0.833
8	35±1	2.07	0.431	0.893
9	40±1	2.14	0.446	0.954
10	45±1	2.21	0.460	1.017
11	50±1	2.27	0.473	1.074
12	55±1	2.35	0.490	1.152
13	60±1	2.44	0.508	1.240

From the above table, it can be seen that the maximum power obtained two Peltier modules connected in series was about 1.25W.

Table 3.3: Power vs Speed of Vehicle with Peltier Modules in Parallel

Sl. No.	Speed in Kmph	Voltage in Volts	Current in Amps	Power in Watts
1	0	0.87	0.181	0.158
2	5±1	0.91	0.189	0.173
3	10±1	0.92	0.192	0.176
4	15±1	0.94	0.196	0.184
5	20±1	0.96	0.2	0.192
6	25±1	0.98	0.204	0.201
7	30±1	0.99	0.206	0.204
8	35±1	1.01	0.210	0.212
9	40±1	1.03	0.214	0.221
10	45±1	1.05	0.218	0.229
11	50±1	1.06	0.221	0.234
12	55±1	1.08	0.225	0.243
13	60±1	1.12	0.233	0.2613

From the above table, it can be seen that the maximum power obtained two Peltier modules connected in parallel was about 0.26W.

The graph in Fig. 3.1 shows the Comparison between the speed of the vehicle and the power output produced in the above-mentioned configurations.

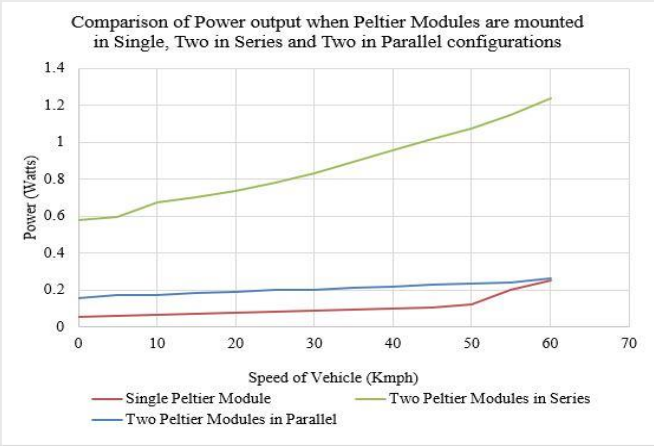

Fig. 3.1: Graph of Speed vs Power in Single, Series and Parallel Configurations

It is apparent from the above graph that as the speed of the vehicle increases, the power output from the Peltier modules for all configurations increases. The reason for the increased power output at higher speeds is that as the speed of the vehicle increases, the silencer heats up to higher temperatures, and as the speed is high, air at the front of the vehicle effectively cools the other surface of the modules. This causes maximum temperature difference between the module surfaces, yielding the best results. The graph also shows that there is substantial improvement when more than one Peltier module is utilized and that the performance of series combination is much better than the other two configurations.

IV. CONCLUSION AND FUTURE SCOPE

A large amount of power is produced by engines. This power is utilized by humans to meet their energy needs. However, there is a large quantity of power going wasted and unutilized. This work reclaims some amount of that wasted power. Through this work, a maximum power output of around 1.25W was obtained from the Peltier module setup. The methodology of this work can be implemented on any machine with an engine. As all engines have silencers and exhaust gases escaping from them, any energy going wasted through the silencer can be easily extracted for future usage. The method can be implemented on any automobiles like cars, bikes, scooters, trucks etc.

Peltier modules are currently implemented on satellites, where the drastic temperature differences between the surfaces facing the sun and the surfaces which do not, prove as the ideal situation for the implementation of the same.

Improvements that can be made to the present work to further enhance the output include:

- Connection of more Peltier modules on the setup.
- Utilization of liquid cooling on the Peltier module setup instead of air cooling.
- Use of Peltier modules made of PbTe.

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