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WASTE HEAT UTILIZATION SYSTEM FOR AUTOMOBILES

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Abstract — *a significant amount of energy we consume each year is rejected as waste heat to the ambient. Conservative estimates place the quantity of energy wasted at about 70%. Converting the waste heat into electrical power would be convenient and effective for a number of primary and secondary applications. In recent years, environmental issues like global warming, emissions, etc., are the limiting factors for the energy resources that are required to generate electric power. Thermoelectric generators have emerged as a promising and green technology source due to their diverse advantages. Thermo-Electric Generator directly converts Thermal energy into Electrical energy. The application of this green technology in converting waste heat energy directly into electrical energy can too improve the overall efficiencies of energy conversion systems. In this report we attempt to extract the waste heat energy from an automobile IC engine and then convert it into useful electrical energy.*

Keywords*-Peltier Effect; Seebeck Effect; Thermoelectric Cooler; Thermoelectric Generator; Heat extraction system; Heat energy from exhaust gases; Cabin Cooling and Heating; Simple yet effective system on concept basis.*

I. INTRODUCTION

Extracting the waste heat energy developed by an internal combustion engine and harnessing it into useful energy is touted to be the next big breakthrough in automobile advancement. It not only presents a potential source of reducing the harmful emissions, but also acts as a reservoir of subsidiary energy which can be used to support the alternator and the car battery.

Thermoelectric generation of electrical energy can be derived using various methods like the use of a thermoelectric module, heat pipes etc. Hence, we have used 3 thermoelectric modules made of semiconducting material (Bismuth-Telluride) to generate useful electricity from the waste heat surrounding the pathway of the exhaust gases. The hot side of these modules are in contact with the surface of the exhaust pipe and the cold side will be attached to a precision manufactured aluminum heat sink, thereby providing the necessary optimal temperature difference. This entire apparatus will be tightly mounted between the exhaust manifold and catalytic converter, before the muffler, using metal clamps (mild steel). We have thereafter incorporated the energy derived from this model into charging a battery which subsequently runs a Peltier module in order to regulate the cabin temperature of the car.

This study focuses on developing and implementing an exhaust gas heat recovery model which will successfully convert the waste heat around the exhaust into useful electricity and studying important parameters like where the temperature difference will be most favorable, what will be the model's effect on the car's exhaust back pressure and how efficiently heat can be extracted from the proposed region. It is an important step in understanding and exploring a widely talked about proposition of increasing an engine's efficiency in the eco-friendliest manner possible.

II. CONCEPT OF WORKING

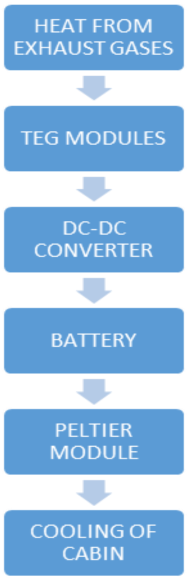

Figure 1. Flow of the system

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III. WORKING

3.1 Experimental Apparatus

3.1.1. Thermoelectric Module

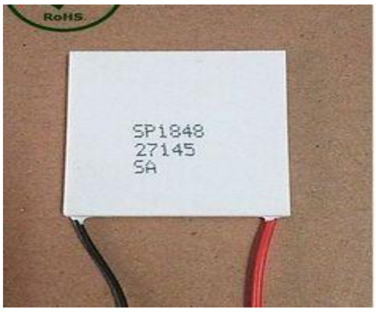

Figure 2. TEG Module

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

3.1.2. Heat Sink

Figure 3. Heat Sink

The aluminum heat sinks fins 22 in numbers and spread over 90mm x70mm area with 0.5mm thickness which is shown in fig. Three heat sinks are used in the experimental setup. Aluminum heat sink is used because it has high thermal conductivity it is easily available at low cost.

3.1.3. Battery:

A lithium ion battery of 12V 7Ah capacity is used in order to store energy that is generated by the thermoelectric modules. RELICELL SSP-12-7 reliable energy storage, maintenance free battery that is being used is a high-quality battery which has a long float and cyclic life span.

3.1.4. Peltier module:

Module specifications:
Dimensions: - 40mm x 40mm x 3.3mm
Color: - White
V_{input} max: =12V
Max power consumption = 92W
T_{max} (hot side) = 90°C | Tmin (cold side) = 6°C

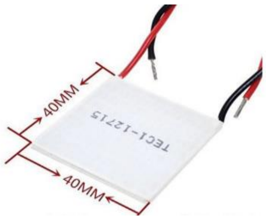

Figure 4. Peltier cooler

3.1.5. Battery operated fan:

Figure 5. Simple Cooling Fan

A portable, handy desk fan with a variable impact angle of 180°C(foldable) is used for impacting air onto the cold side of the Peltier module, which will thereby reduce the temperature of the air. The fan has an inbuilt 4000 mAH battery which is rechargeable and its motor can throw air at 3 variable speeds.

3.1.6. Active Heat Sink:

Figure 6. Heat Sink with CPU Fan

Since the temperature of the hot side of the Peltier module can become very high (80-90°C), the conventional aluminum heat sink may not be as effective in dissipating the heat to the atmosphere. Hence, a custom CPU cooler heat sink with cooling fan had to be used in order to derive the desired results from the module.
Heat sink dimensions: -85.4mm x 85.4mm x 41.5mm
Fan size: - 70mm x 70mm
Rated voltage of fan =12V DC

3.2 Setup and Installation:

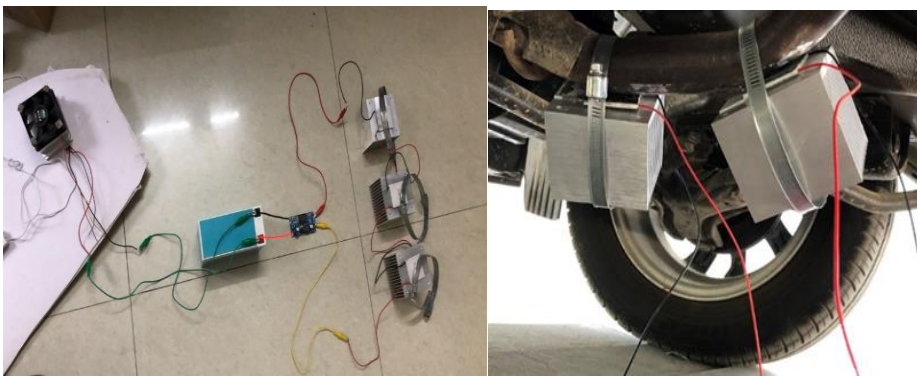

Figure 7. Connection of Cooling and Heat Extraction

When these gases pass through the section of exhaust pipe before the catalytic converter, it provides the attached modules with enough amount of heat on the hot side facing the pipe. The aluminum heat sink attached to the cold side of the fin is instrumental in dissipating this heat from the cold surface. The heat sink, in driving conditions, shall be more effective in dissipating heat as when the vehicle is moving, the atmospheric air impacts the fins which carries the heat. Thus, an effective temperature difference is established between the hot and the cold surface of the semiconducting thermoelectric modules which causes the electrons to migrate from n-type to p-type material and the holes to migrate from p-type to n-type within the module, thereby generating an E.M.F. which causes electricity to flow.

Significant amount of output voltage is obtained due to multiple modules being connected in series electrically. This output voltage is of direct current nature and it is also of fluctuating nature (varying) as the temperature difference is not constant. Thus, a stable/step-up converter (depending upon load or purpose of use) is used so that no matter how drastic the fluctuations are, it will always supply steady voltage to the load.

From the converter, the electricity is being fed to the Lithium ion battery which serves the purpose of recharging this battery every time the car is being driven. This battery, in other words, can be termed as an energy reservoir which is storing the generated electrical energy. The battery further runs the Peltier module placed on the before mentioned foam sheet cutout.

The Peltier module is a thermoelectric module which operates on the Peltier effect, which is the direct opposite of the principle on which the thermoelectric generators work, i.e., the Seebeck effect. The Peltier effect is a thermodynamic effect in which a temperature difference can be obtained by providing voltage to the module. A Peltier module is placed in the cutout with its cold side facing the cabin and the hot side exposed to the atmosphere. Due to the very high temperature of the hot surface, custom made, commercially available active heat sink with a cooling fan is attached using heat conducting paste and heat conducting adhesive.

The input wires of this cooling fan and the Peltier module are drawn out of the cutout and connected to the discharged ports of the battery by using separate insulated positive and negative wires and alligator clips. Another regular, passive aluminum heat sink is attached on the cold side facing inside the cabin so that the surface area of the cooled down temperature to be made available for forced convection increases. The portable fan is placed on the tray in such a direction so that it faces the heat sink diagonally upwards. Doing this will reduce the temperature of the air in the upper region of the cabin and as the temperature increases, it will cause this region of the air to heat up and settle down inside the cabin as the density of the air will increase. Subsequently, the air that is accommodated by the upper region of the cabin will cool down again. Therefore, an entire cycle of recirculation of air can be achieved which effectively will reduce the temperature of the cabin.

3.2.1 Car Specifications:

MODEL NAME	TATA TIAGO 1.2 REVOTRON XZ
FUEL TYPE	PETROL
ENGINE	1.2 L 84 bhp 12 V REVOTRON ENGINE
STROKE LENGTH	1199 cc
MAX POWER	84 bhp @ 6000 RPM
MAX TORQUE	114 Nm @ 3500 RPM
NO. OF CYLINDERS	3
TRANSMISSION TYPE	MANUAL

Table 1. Car Specification

IV. RESULTS

Based on the working explained earlier, the following readings were observed:
*all readings shown below were taken when the engine was operating between 1500-2000 rpm

4.1.0 Relationships observed between various observed values:

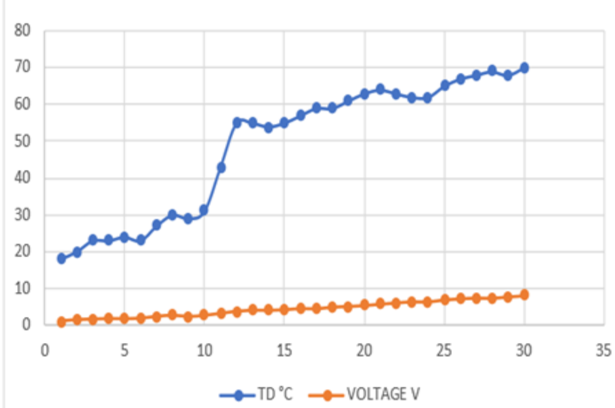

Figure 8. Relationship of Td vs Voltage

Based on the experimental values mentioned in table no. 4, a relationship between temperature difference (Td) and generated voltage is observed. The TEGs being used for our experiment works up to a temperature range of 120°C. At an engine speed of 1500-2000 rpm, we observe the temperature difference to increase from 18°C to 55°C in 15 mins. It is also observed that the voltage being generated by the modules also increases from 1.01 V to 4.02 V in 15 mins. Prolonged experimentation reveals the same trend to be followed up to 30 mins (Td = 70°C, V=8.02 V). We have thus plotted a graph which shows that a proportional relationship exists between the temperature difference obtained between the hot and the cold surface of the thermoelectric generator and output voltage generated by them. Hence we can conclude that "with due course of time, as the temperature difference increases, the output voltage also increases proportionally."

4.1.1: Relationship between V & Time:

Another relationship between the running time of the engine (mins) and generated output voltage (V) is observed based on the experimental readings mentioned in table no. 4. The voltage generated by our modules after the engine had been running for one minute is 1.01V. After 5 min the observed reading of voltage was up to 1.62V. As the running time increase up to 10 min, the temperature of the exhaust pipe showed a steep increase which generated an output voltage of 2.56V. At 20 mins, the voltage generated was up to 5.29V and a similar raise is observed at 30 mins (8.02V). When we plotted a graph for the following readings (time interval =1 min, for accuracy), we observed the relationship to be directly proportional. Thus, as the run time of the engine increases, voltage generated also increases.

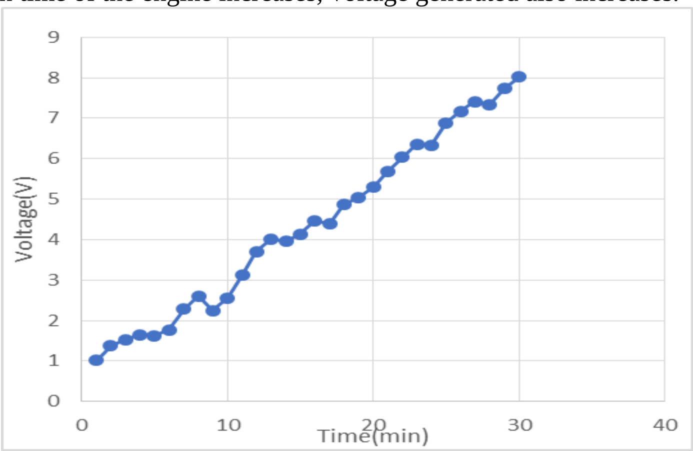

Figure 9. Relationship of Voltage vs Time

4.1.2: Relationship between Time & T_{d}:

In order to understand the fundamental reasoning behind the increase in voltage generation over due course of time, the above shown graph is instrumental. A particular and clear relationship can be established between the run time of the engine and the temperature difference (Td = Th¬ – Tc). The increase in the temperature difference is due to more volume of hot exhaust gases passing through the exhaust pipe, which increases the temperature of the exhaust pipe periodically, thereby increasing the surface temperature of the hot surface of the thermoelectric generator. This is why at 5 mins, Td = 24°C whereas at 25 mins, Td = 65°C. Hence, we can conclude that the relationship between engine run time and the temperature difference between hot and cold surface is directly proportional.

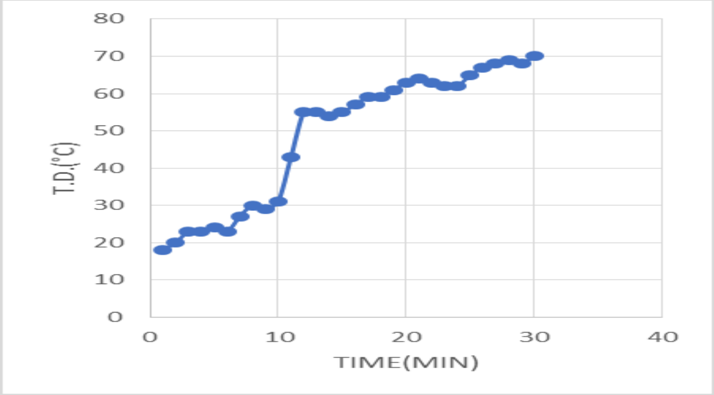

Figure 10. Relationship of Td vs Time.

4.2 Observations:

TIME (MIN)	T_h(°C)	T_c(°C)	T_d (T_h-T_c) (°C)	VOLTAGE (V)	CURRENT (AMP)
1	71	53	18	1.01	0.006
2	82	62	20	1.37	0.09
3	86	63	23	1.53	0.1
4	85	62	23	1.65	0.09
5	85	61	24	1.62	0.12
6	89	66	23	1.77	0.16
7	98	71	27	2.28	0.18
8	102	72	30	2.6	0.14
9	100	71	29	2.24	0.16
10	101	70	31	2.56	0.22
11	115	72	43	3.12	0.26
12	125	70	55	3.71	0.3
13	130	75	55	4.02	0.27
14	127	73	54	3.96	0.33
15	126	71	55	4.13	0.32
16	131	74	57	4.47	0.38
17	135	76	59	4.39	0.40
18	135	76	59	4.86	0.41
19	136	75	61	5.04	0.42
20	134	71	63	5.29	0.45

Table 2. Output Data

4.3: Local cooling inside the car's cabin:

As explained earlier, we intended on achieving a drop-in temperature inside the cars cabin. To achieve this, we use the principle of forced convection over a relatively cold surface, which ultimately causes a drop-in temperature of the air trapped inside the cabin and recirculation of the air can be achieved.

As seen in the figure below, our preliminary examination resulted in the observation that when the engine is shut off and the car is parked (12 pm), we found that the temperature of the air inside the parked car is touching a peak temperature of 42°C. The temperature of the space inside the cabin is expected to rise even further during the afternoon due to extreme climatic conditions. The Peltier module that we had attached over the foam sheet cut out which seals the cabin completely, is shown. It is observed that right after the input terminals of the Peltier and the active heat sink are connected to the battery, the temperature drop on the cold surface of the Peltier starts becoming noticeable.

Figure 11. Considerable drop in 20 minutes

Similarly, after functioning for 20 mins, a temperature drop up to 36.8°C was achieved locally. That makes the total effective temperature drop (local) of air inside the cabin 5.2°C. Due to the climatic temperature being extremely harsh, the heat radiated inside the cabin from various sources like seat covers, plastics, instrument board of the car etc. impacted on the result significantly.

V. CONCLUSION

This project aims to find a possible way to recover waste heat from the exhaust of am I.C. Engine as well as to show a running demonstration of harnessing and productively utilizing this waste heat energy.
Experimentally it is found that when three thermoelectric generators are connected in series, the generated electrical energy can directly be utilized to run some auxiliary devices (mobile charger, LED lights) found in an automobile or may be stored in an energy reservoir (battery) and used later.
The auxiliary loads including the cooling Peltier module can be powered from this battery thereby reducing the load on the car's parent battery.
The generated voltage, if harnessed substantially can be used in recharging the car's /bike's battery thereby reducing the size and the load on the alternator, resulting in reduced weight of the vehicle and space occupied in the vehicle.
The proposed system can successfully be used as an electrical power generating system which is of passive state (no moving parts) and the method of generation is eco-friendly.

VI. NOMENCLATURE

Th: Temperature of hot side
Tc: Temperature of Cold Side
Td: Temperature difference of Th and Tc
V: Voltage
A: Current
MAH: miliampere hour

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