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Potential of Waste Heat Recovery using Thermo-Electric Generator

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Abstract — *A significant amount of energy is wasted in automobile in the form of exhaust gas. The amount of lost energy is almost 65%, according to conservative estimations. For many main and secondary applications, it would be practical and efficient to convert waste heat into electrical power. Environmental concerns, such as global warming, emissions, etc., have recently become the limiting considerations for the energy resources needed to produce electricity. Over the time, various alternate methods for obtaining and utilizing this energy have been proposed, each having advantages and disadvantages of their own. Recent advancements in thermoelectric generator technology make this method of recovering low grade energy quite effective. Thermal energy is immediately converted into electrical energy using thermoelectric generators. Thermoelectric generators use the principle of seebeck effect. Furthermore, TEGs may be produced on a wide range of substrates, including silicon, polymers, and ceramics. This paper outlines the knowledge about potential of thermo-electric generators to recover waste heat in automobiles.*

Keywords *- Waste Heat Recovery; Seebeck Effect; Peltier; Thermoelectric Generator; Exhaust Gases.*

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I. INTRODUCTION

According to estimates, only one third of the energy is actually utilised for practical purposes, with the other two thirds being wasted as heat [1]. A typical internal combustion engine, especially one used in the automobile sector, has a highest efficiency of about 25%, with the leftover 75% of energy being wasted as waste heat from exhaust fumes and engine coolant [2]. The engine efficiency can be improved by recovering this waste heat [3]. Numerous studies have looked into the recycling of waste heat from internal combustion engines using different methods. Thermoelectric technology is among the most efficient strategies to utilise this surplus heat [4]. This is because of continuous advancements in materials used in thermoelectric modules [5]. Due to high dependency on volatile fossil fuels and awareness about environmental effects, internal combustion engines will dominate in the future for very long time. The semiconductor Seebeck effect enables thermoelectric devices to convert heat into energy instantly, which is extremely intriguing for systems with the highest dependability for heat waste recovery [6]. Several pairs of alternating p- and n-type semiconductor blocks typically make a thermo-electric generator. TEGs can produce power wherever there is a temperature difference. Waste heat recovery not only increases the efficiency but also reduces air pollution [7]. TEGs are also environment friendly as they produce no sound pollution [8].Thermoelectric generators can be used to run auxiliary loads which reduces the weight of the engine [9]. Figure 1 shows the Seebeck effect on which thermo-electric generators are working [10].

The ratio of the heat flow into the module (qh) to the produced electrical power (P) is a natural measurement of the conversion efficiency. If there is little or no heat loss between the hot and cold sides, i. e., if q_h equals the sum of qc and the converted power P, it can also be derived from the heat flow on the cold side, qc[11][12].

$$\eta = \frac{P}{qh}$$

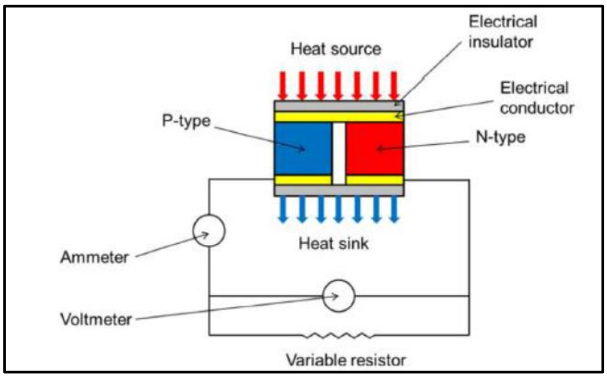

Figure 1 Seebeck Effect

The performance of TEGs is governed by the variation in temperature between the generator's two sides. The electrons that surround the metal atoms on one side of a piece of metal will have more energy than the equivalent electrons on the other side if one side of the metal is heated while cooling the other. This suggests that the heated electrons will be more energetic than the cold electrons. The thermocouple's two materials' electrical resistivity ρ_p and ρ_n, thermal conductivities, λ_p and λ_n, and Seebeck coefficients, α_p and α_n, can all be used to express Z, the factor of merit of the TE materials [13]. A typical TEG module with several thermoelectric couples made of p-type and n-type TE elements is shown in Figure 2[14].

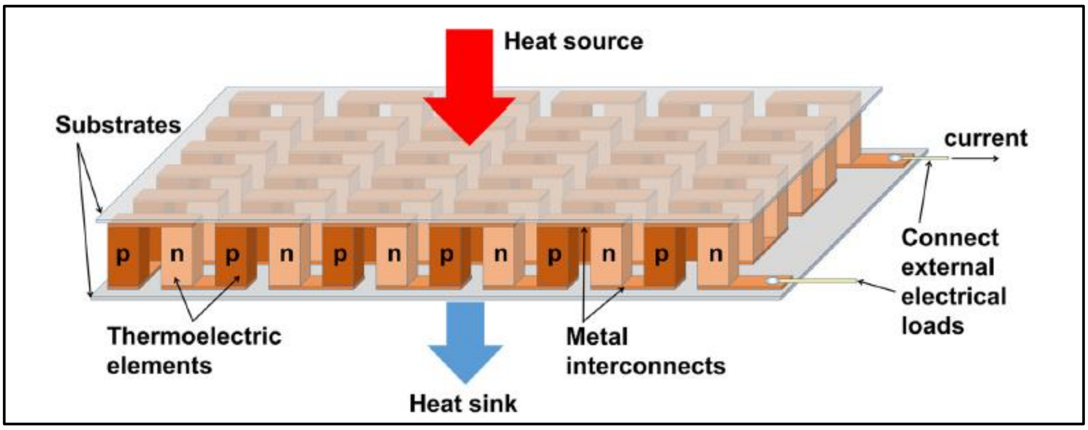

Figure 2 Typical TEG Module

The electrical copper plates surround the n- and p-type thermoelectric supports. These copper tabs complete the electrical circuit when paired with an external electrical load resistance [15]. These supports are fastened to alumina-based ceramic surfaces (Aluminum Nitride). The engine coolant source, which is kept at a steady temperature of 100 ℃, is in thermal touch with the colder side. To facilitate heat transfer from the heated exhaust gas to the hot end of thermoelectric (TE) connections, a plate fin type heat exchanger is inserted in the TEG. A schematic of a typical thermoelectric couple is shown in Figure 3.

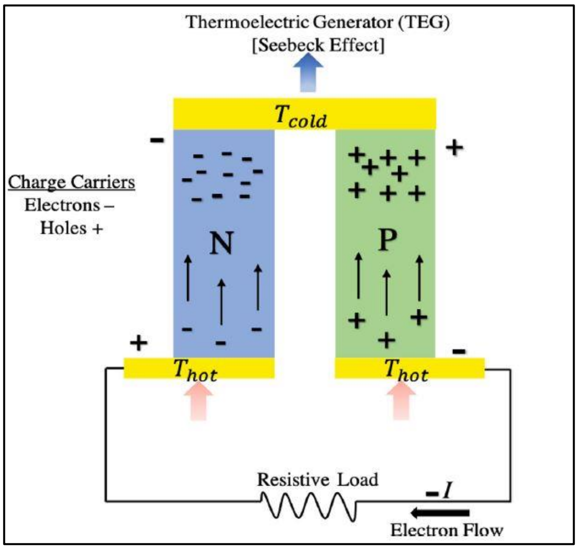

Figure 3 Schematic of Thermocouple

This research focuses on thermoelectric generators that can effectively convert the exhaust's waste heat into usable electricity while also examining crucial factors like the ideal location for the temperature difference and the efficiency of heat extraction. It is a crucial step in knowing and investigating the commonly discussed idea of improving an engine's efficiency in the most environmentally friendly way possible.

II. EXPERIMENTAL SETUP

To verify the results from the analysis, an experimental setup was especially built. A thermoelectric module is attached to an aluminum heat sink, which is positioned inside a channel made of aluminum. A heat gun that simulated exhaust gas is used to supply heated air to the heat sink through the duct. A full hot-side feed is insulated by high-temperature insulation. A specially fabricated aluminum channel is utilized on the cold end as a heating element. Cooling water is pumped through the cold-side passage by a tiny water pump with an established volumetric flow rate. Four K-type thermocouples are positioned at the inlets and outlets of the ducts to detect the temperatures of the heated and cool fluids entering and leaving them.

For the experimental testing, a model SP1845-27145 Bismuth Telluride thermoelectric device with physical dimensions of 40 mm x 40 mm x 3.5 mm was used. A picture of the device, which contains 127 pairs, is displayed in Figure 4.

Figure 4 Thermo cooler Peltier Module

A testing component was built so that A well-known thermal source could be placed to the device's "hot" side. The efficiency of the thermoelectric device can be determined by monitoring the output power through a load and can be determined as below [16]:

$$\eta = \frac{\text{Pout}}{Qin}$$

Where, η = thermal efficiency
P_{out} = device's determined power production (watts)

Q_{in}= device's determined intake heat (watts)

$$Qin = \frac{(Vin)^2}{R}$$

Where, V_{in} = Heater Voltage and
R = Resistance of heater (fixed value)

$$Pout = Vout.Iout$$

For testing purposes, a unit was built to house the thermoelectric generator. Assembly with a resistive heater attached to the hot side to simulate waste heat and a water-circulating cooling block connected to the cold end of the TEG for heat dissipation is shown in figure 5.

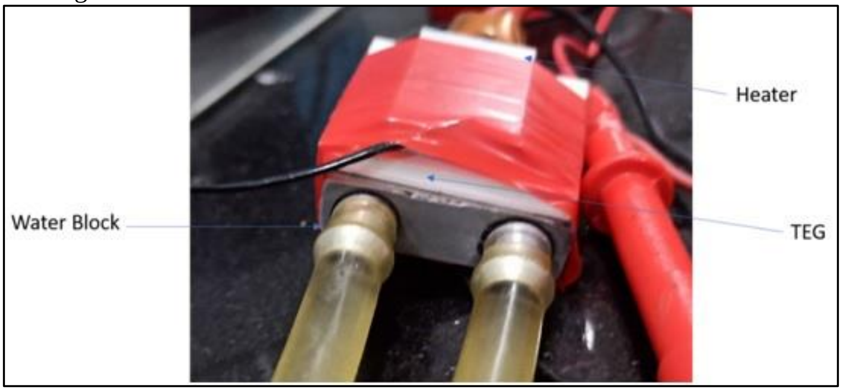

Figure 5 Assembly of Heater-TEG-Water Block

Complete experimental setup is shown in figure 6. It consists of several items including thermo-electric device. A pump and water container are used to circulate the water on cold side. Heater is used to generate temperature difference. Power supply is used to provide power to both the heater and water pump. Resister is used to provide load.

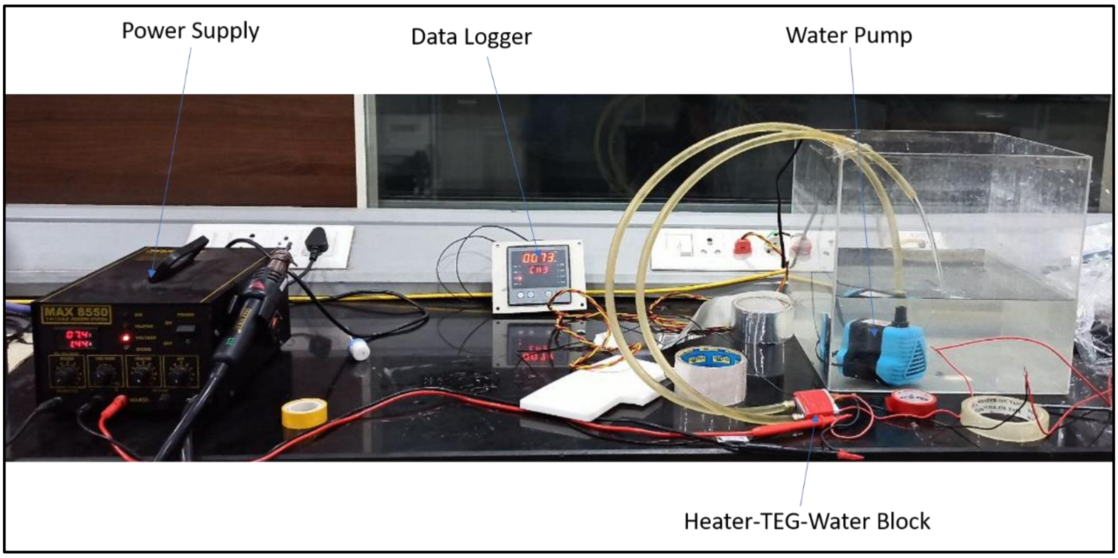

Figure 6 Complete Experimental Setup

III. RESULTS AND DISCUSSION

An experiment was conducted where temperature difference between hot and cold side was maximum operated till 114.88 °C. And results are as follow:
Fixed Resistance of Heater (R): 10Ω

Table 1 Experimentally Collected Data

Heater Voltage	Temp. Hot	Temp. Cold	Temperature Difference of	Heat Input	Voltage of power	Ampere of power generated	Maximum Power	Maximum Efficiency (%)

(V_{in}) (V)	side (°C)	side (°C)	Hot & Cold Side (ΔT (°C))	Qin (watts)	generated (V_{out}) (V)	(I_{out}) (Amp)	Generated Po_{ut} (W)	
12	42.33	22.03	20.3	14.4	0.57	0.18	0.1026	0.7125
14	47.05	22.15	24.9	19.6	0.75	0.3	0.225	1.147959
16	57.13	22.18	34.95	25.6	1	0.33	0.33	1.289063
18	67.42	22.77	44.65	32.4	1.25	0.45	0.5625	1.736111
20	78.41	23.11	55.3	40	1.65	0.5	0.825	2.0625
22	91.25	23.15	68.1	48.4	1.84	0.68	1.2512	2.585124
24	102.7	23.55	79.15	57.6	1.92	0.74	1.4208	2.466667
26	114.88	23.88	91	67.6	1.99	0.85	1.6915	2.502219

Eight different tests were conducted using this experimental setup for different temperature differences. The input heater voltages were 12,14,16,18,20,22,24 and 26 volts. The temperature difference was increased by increasing the heater voltage. The power output and efficiency were measured for the different heater voltages and temperature range. The power output varies with the output voltage and it varies for different temperature ranges. The relationship between temperature difference and output voltage is shown in figure 7 whereas relationship between temperature difference and current is shown in figure 8. The efficiency increases with the increase in temperature difference.

Y axis: Temperature (°c) **X axis**: Volatge(V)

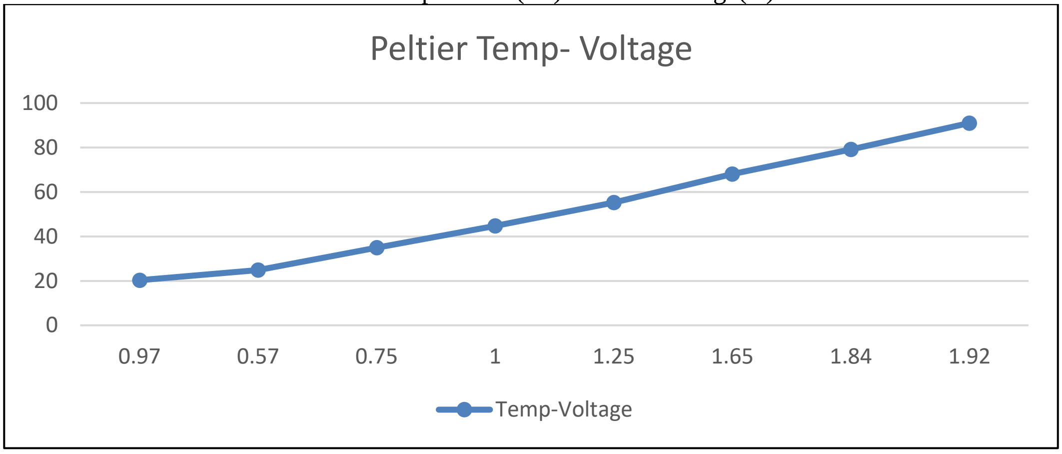

Figure 7 Output Voltage of Thermoelectric Device

Y axis: Temperature (°c) **X axis**: Current (MA)

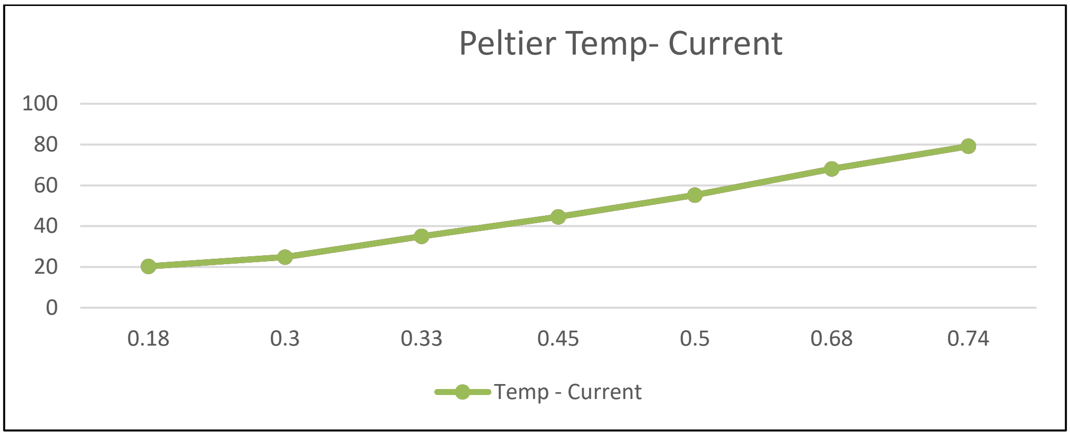

Figure 8 Output Voltage of Thermoelectric Device

IV. CONCLUSION

The purpose of this research is to identify a potential method for recovering waste heat from an internal combustion engine's exhaust and to present a working example of how to capture and effectively use this waste heat energy.Experimental findings indicate that when thermoelectric generators are being used, the electrical energy produced can either be used immediately to power some auxiliary equipment (such as a mobile charger or LED lights) found in an automobile, or it can be stored in a battery and used at a later time.The instantaneous power generation and efficiency of a commercial thermoelectric device are being measured using an experimental setup that is described in this work. Findings are given for a specific Bismuth Telluride thermoelectric device (SP1845-27145).In the experimental setup, the load resistance is fixed, and both the Peltier temperature-voltage and Peltier temperature-current plots are presented. An efficiency of 2.58% and an output power of 1.25 watts were obtained with a temperature difference of 68.1°C during testing.Greater efficiency would be produced by greater temperature differences.Future testing with greater temperature differences is planned; however the current testing was effective under the tested circumstances.

V. NOMENCLATURE

TEG: Thermo-Electric Generator
q_h:heat flow into the module
P_{out}: Maximum Power Generated
ΔT: Temperaturedifference hotside of and Cold Side
V:Voltage
Amp: Ampere
W: Watt

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