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THERMOELECTRIC POWER GENERATION FROM AUTOMOBILE ENGINE EXHAUST: A REVIEW

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ABSTRACT

The requirement of electricity is increasing every day and now a days, automobile is playing an important role in transportation. There are various methods to reuse the waste heat radiated through vehicle in the form of exhaust. For this, in this paper Peltier module is used. The whole project is based on Seebeck effect which states that "when two ends of two dissimilar metal conductors are exposed to two different temperatures, the electrons at hot junction at higher thermal velocities diffuse into the cool junction". Peltier module is a device made up of various p-type and n-type semiconductors connected in parallel to each other. It has hot and cold junctions. The hot junction is in contact with the exhaust and the cold junction is in contact with the atmosphere or some coolant for producing temperature difference, this temperature difference results in voltage generation. The voltage produced is further amplified like various electrical circuits like voltage boosters, transformers, rectifiers, inverters, etc. By all these arrangements the final voltage can be applies for useful appliances as per the requirements.

Keywords: Power generation, peltier module, aluminium block, heat extraction, heat transfer.

I. INTRODUCTION

In this modern era, the need for electricity increases day by day and also requires efficient electric power generation methods. The conventional and most popular method of power generation is by Power Plants approximately 60 to 80% and rest by renewable energy sources[4]. But all these power generation systems requires high costs for their operation and are also not as much efficient. In this century, transportation have become much easier by automobiles (commercial & non-commercial). To power these automobiles a greater amount of heat is required, which can be generated by combustion of fuels, but maximum amount of heat is lost through exhaust systems (about 35%), as well as some amount from cooling systems and lubrication systems and through extended surfaces (called as fins)[8].

According to research and survey by Research & Development department, there are many solutions implemented to recover the waste heat into some useful application, one of which is power generation. The conversion of waste heat directly to electric power is possible and can be done by introducing an electronic device most popularly known as "Peltier Module" or "Thermoelectric Generator". This module was invented by the well-known scientist "Thomas John Seebeck" in the year 1821. The working principle is "Seebeck effect"[1]. The heat from exhaust system is utilized for generation of electrical power by taking into account module's working methodology. This module is advantageous and efficient over conventional methods and also utilizes maximum amount of waste heat energy for generation of voltage.

Table 1. Symbols and Notations

SN.	Symbols	Notations
1	α	Seebeck coefficient
2	λ	Thermal conductivity
3	A	Total surface area of block parallel to central axis
4	A_m	Surface area of Peltier module in contact with the block
5	dT_m	Temperature difference in Peltier module
6	dx	Thickness of Peltier module

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7	k_a	Thermal conductivity of exhaust pipe
8	k_b	Thermal conductivity of aluminium block
9	k_m	Thermal conductivity of Peltier module
10	L	Length of the block measured along the central axis
11	P	Electrical conductivity of Peltier module
12	Q	Total heat transfer from exhaust pipe to the hot side of the Peltier module
13	r_1	Inner radius of the exhaust pipe
14	r_2	Outer radius of the exhaust pipe
15	r_3	Outer radius of the block
16	t_a	Temperature of ambient air
17	t_1	Temperature at the end of exhaust pipe radially
18	t_g	Temperature of exhaust gas

II. PELTIER MODULE

Peltier device is made up of number of p-type and n-type semiconductors connected in parallel to each other and it have two main junctions say, "hot" and "cold". These two junctions are exactly opposite in direction to each other. Hot side is always applied to the heat source so that it can extract heat and the cold side can be connected to the cooling medium such as, a water cooling and oil cooling or it can be exposed to the atmospheric air or most probably it is connected to aluminium fins for better convective heat transfer. The material used to make peltier module is Bismuth Telluride (Bi_2Te_3), Sb_2Te_3 for p-type and Bi_2Se_3 for n-type material[2][7][11].

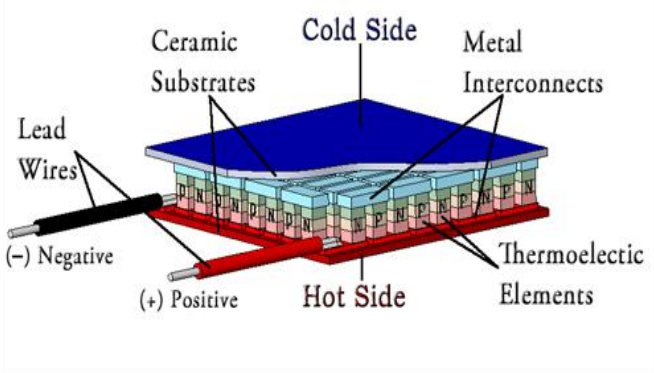

Figure:1 Construction of Peltier Module**.**

Figure:2 Peltier Module**.**

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III. SYNTHESIS OF BISMUTH TELLURIDE (BI_2Te_3)

Initially, black precipitation of Bi_2Te_3 nano-powder was existed by mixing the tellurium and bismuth nano particles and is stirred at 423 K for 1 hour. His mixture was allowed to cool at room temperature. The mixture is then centrifuged and washed with ethanol 5 times compulsorily and the oven is used to dry this solution at 343 K till 1 day. Through the study the following reaction is known as (ST-Bi_2Te_3). The reaction is repeated by adding (0.6 g of NaOH) and also by adding (0.2 g of EDTA or PVP). Through this synthesis the following nano structure is observed as shown below[13].

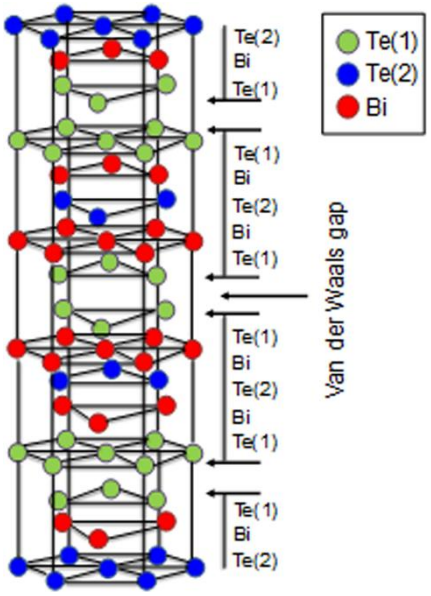

Figure:3 Hexagonal Nano-Structure of Bismuth Telluride**.**

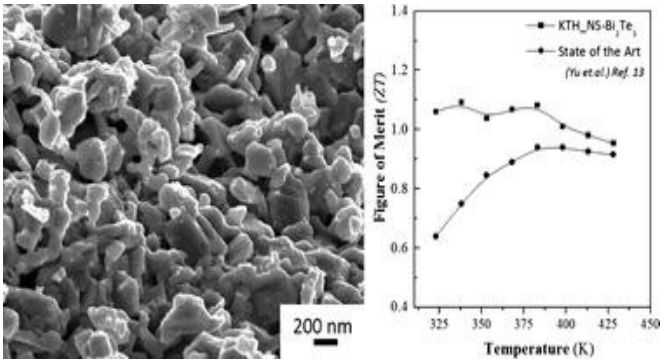

Figure:4 Microscopic Nano-Structure of Bismuth Telluride**.**

a) Properties of Bismuth Telluride

Table 2. Symbols and Notations

SN.	Properties	Specific Value
1	Mass	800.761 g/mol
2	Density	7.7 g/cm^3
3	Figure of Merit	1.12 maximum value at 300 K
4	Seebeck Coefficient	287 M-v/K
5	Thermal Conductivity	1.20 W/m-K
6	Electrical Conductivity	1.1 x 10^5 S-m/m^2

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IV. WORKING OF PELTIER MODULE

A Peltier module or thermoelectric generator works on the principle commonly called as "Seebeck effect". Seebeck effect states that "*In two dissimilar materialswhen the heat gets transferred from hot junction to the cold junction it produces electrical voltage."* By the reference of this statement it means that the amount of heat gets transferred from hot side to the cold side of the module by the mode of heat transfer commonly called as heat conduction. This heat is conducted through the material which is a semiconductor. The tendency of this semiconducting device is to unstable due to heating and this instability of the electrons results in production of voltage but of a small amount depending upon the extraction of heat from the heat source. The voltage generation is possible only if the minimum temperature difference between the hot side and cold side of the module is 27 ºC[3][5][10].

The voltage can further be amplified as per the required applications by using various electrical circuits such as voltage boosters, inverters, transformers, rectifiers, etc. The actual performance of this module is entailed by a term called "*figure of merit (ZT)*". The figure of merit is a numerical expression which represents the performance or efficiency of the electronic device[13].

$$ZT = \alpha^2 p / \lambda$$

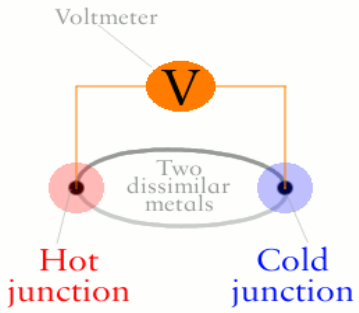

Figure:5 Seebeck Effect**.**

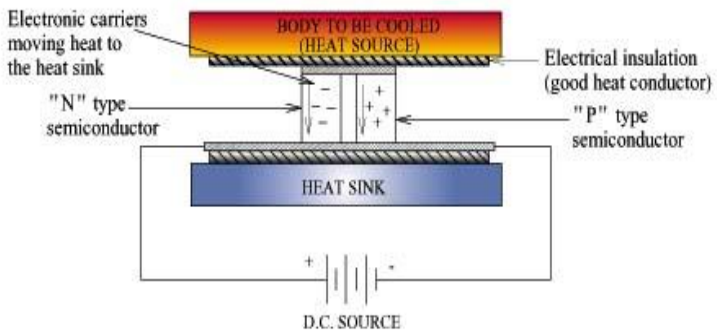

Figure:6 Working Principle of Peltier Module**.**

The peltier modules are installed at the automobile exhaust generally before the muffler or silencer. The direct contact of the peltier module with the silencer can be harmful and can cause damage. So, this problem can be overcome by placing a peltier module on the metal block or any material which have higher thermal conductivity. Aluminium has a good thermal conductivity and is best suited for the peltier module. This aluminium block fits on the exhaust gas pipe and on the aluminium block the peltier module is fitted with the help of sticking substances which can conduct heat such as grease. According to survey about 30 to 40% of heat is lost through the automobile exhaust, the module can utilize about 10 to 20% of the heat for the power generation. The direct conversion of heat energy electrical power cannot be stable or in purified form, this issue can be solved by installing various electronic devices to produce a stable output which can be utilize for required application.

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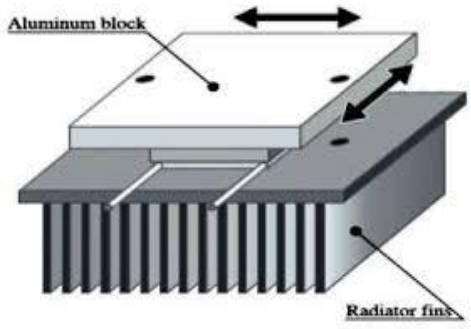

Figure:7 Peltier Module on Aluminium block for better heat transfer**.**

V. HEAT TRANSFER THROUGH ALUMINIUM BLOCK

Heat transfer is the base for power generation. Transfer of heat takes place mainly in three modes viz. *Conduction. Convection* and *Radiation.* These three modes allows the heat to transfer in solids, liquids and gasses. Heat transfer is nothing but the energy interaction between two substances which are in physical contact with each other. Heat transfer deals with the rate at which energy transfer takes place from one equilibrium state to another. As according to thermodynamics, energy is a path function which deals with the analysis of a process operating in a system and is independent of equilibrium states. In this paper we aimed to derive a short relation of heat transfer through the hot exhaust gasses to the aluminium block up to the outer end of the block. For simplicity of calculations we assume that the outer square portion of the aluminium block is converted into circular portion having similar surface area as shown in below figure.

Now, if square face is converted to the circular face having same surface area, then.

Total surface area of cylinder = Surface area of block parallel to the central axis

$2\pi rL = 4lL$

$r = 2l / \pi$

Here, ($r = r_3$) outer radius equivalent to the square faced block.

$r_3 = 2s / \pi$ ……..*(1)*

The actual heat conducted in the exhaust pipe and the block is given by,

$Q = [2\pi L.k_a (t_g - t_2) / \ln(r_2/r_1) + 2\pi L.k_b (t_2 - t_a) / \ln(r_3/r_2)]$ ……..*(2)*

By putting the value of 'r_3' in above equation (2),

$Q = [2\pi L.k_a (t_g - t_2) / \ln(r_2/r_1) + 2\pi L.k_b (t_2 - t_a) / \ln((2s/\pi)/r_2)]$

$Q = 2\pi L \{[k_a (t_g - t_2) / \ln(r_2/r_1) + .k_b (t_2 - t_a) / \ln((2s/\pi)/r_2)]\}$ ……..*(3)*

Aluminium block dimensions: 80 x 80 x 50 mm

s = 80 mm = 0.08 m

L= 50 mm = 0.05 m

r_1 = 20 mm = 0.02 m

r_2 = 25mm = 0.025 m

$r_3 = 2s / \pi$

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= 2 x 0.08 / 3.14

$r_3 = 0.0509$ m

By putting all the above values in equation (3), we get

$$Q = 0.314 \{[k_a (t_g - t_2) / 0.2231 + k_b (t_2 - t_a) / 0.9341]\} \ldots\ldots\ldots (4)$$

The above equation is the heat conduction equation in one dimension. But the heat is transferred through four sides of the block to the peltier module is same as the block is symmetric. Then the above equation can be written as:

$$Q = 4 \times 0.314 \{[k_a (t_g - t_2) / 0.2231 + k_b (t_2 - t_a) / 0.9341]\}$$

$$Q = 1.256 \{[k_a (t_g - t_2) / 0.2231 + k_b (t_2 - t_a) / 0.9341]\} \ldots\ldots\ldots (5)$$

Above equation (5) is a simplified form of one heat conduction equation through the exhaust pipe and the aluminium block, here temperature and the conductivity of the materials are variable as per the selection of suitable materials used for transmission of heat in the system.

Now, heat conduction in the peltier module:

$$Q_m = k_m . A_m . (dT_m / dx) \qquad \ldots\ldots\ldots (6)$$

Heat lost from the surface of the aluminium block where peltier modules are mounted:

$$Heat\ Lost = Q - Q_m$$

Percentage of heat lost:

$$(Q - Q_m) / Q \times 100$$

From above value of heat, it can be concluded that this is the minimum amount of heat required to generate the voltage in the peltier module. The value of heat less than this will not result in any voltage generation. This heat transfer in the module can be varied depending upon the modal used and its respective cross-sectional area and thickness. The temperature limits of the module is to be inspected before its use, otherwise this results in severe damage to the modules.

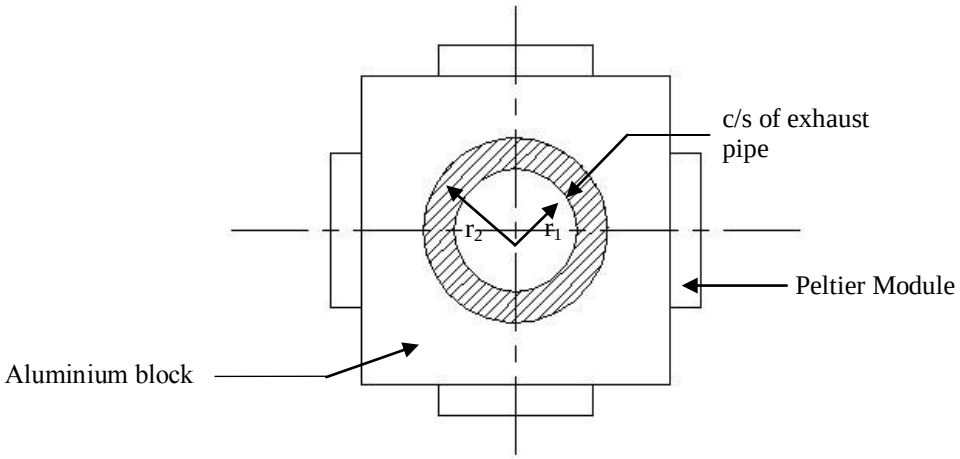

Figure:8 Heat transfer through aluminium block

VI. ALUMINIUM BLOCK AS A HEAT EXTRACTION MATERIAL

Above article 4, entails that the aluminium is used for the peltier modules to rest on it for consumption of heat. Aluminium (Al) is the best material for the extraction of heat from the hot exhaust pipe. It is also possible to install aluminium fins rather than solid aluminium block, but the thing is that as the surface area is greater heat transfer will be greater. Aluminium fins have grooves on their surfaces and hence is not much suitable for module to cover

the surface area evenly. In this case, solid aluminium block having a hollow cylindrical cutting exactly in middle which is to be fixed on the exhaust gas pipe. Aluminium increases the rate of heat transfer and is good for the two main modes of heat transfer i.e. conduction and convection. But this material also have some limitations such as bit can withstand temperatures only up to 660 ºC. The addition of various materials to aluminium like copper, zinc, magnesium, silicon, manganese, chromium, lead, titanium, etc. for the production of aluminium alloys. By making alloys of aluminium the material gets more strong and cannot be easily face any wear and tear. Hence, aluminium is best suited for the heat extraction from exhaust pipe. Below figure shows the views of peltier modules mounted on aluminium block on each side[6].

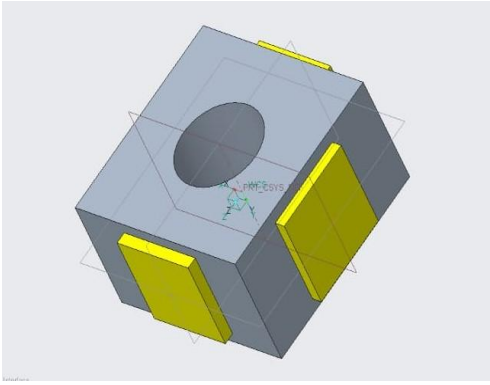

Figure:9 Peltier module (yellow) mounted on Aluminium block (grey)

a) Unique characteristic features of aluminium and its alloys

- It has greater stiffness and strength
- Reduced weight and density
- Properties improve at high temperatures
- Controlled coefficient of thermal expansion
- Heating of materials is controlled
- Electrical conductivity is improved and adaptable
- Improved resistance to abrasion and wear
- Improved depreciation ability[6].

VII. ADVANTAGES AND DISADVANTAGES OF THERMOELECTRIC POWER GENERATION

a) Advantages

- It is noiseless type of power generation.
- The module used is light in weight.
- Cost of modules is less for low temperatures and voltage.
- Voltage fluctuations is less or sometimes zero.
- No maintenance is required.
-

b) Disadvantages

- There is a severe damage to the system due to vehicular accidents.
- Module if once damaged, it is to be changed because it is non-repairable.
- Cost of modules is more at high temperatures and voltage.
- Short circuit can take place if any electrical wire come in contact with the heat source, so proper protection to wires is necessary.

VIII. CONCLUSION

There is an increase in the demand for energy to our day to day activities this project aim is to conserve the electrical energy to some extent, by trapping the waste heat from automobile. The automotive thermoelectric generator is based on the vehicle based heat recovery. The arrangement of thermoelectric module is illustrated for greater output by heating and cooling the opposite sides of peltier module. It mainly works on the principle of Seebeck effect, according to which temperature difference between two dissimilar semiconductors produces in this generated voltage are stimulized with the help of a boost converter. This can also be applicable in appliances such as LED bulbs, CFL bulbs, mobile charging, Battery charging (12 volts to 48 volts depending upon generation voltage). Also, due to this new technique the waste heat can be useful but in the other form of energy. This increases energy saving and can also be called green technology for power generation.

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