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Research Paper

Conversion of Waste Heat from Automobiles into Electrical Energy using Thermoelectric Generators

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ABSTRACT

In our current environment, the expanding interest for energy, with fast consumption of our assets, we should be centered around utilizing economical and sustainable power that produces eco-accommodating energy and lower carbon emanations. So, it is significant that the accessible energy ought to be monitored and used productively. In an internal combustion engine utilized in cars have a limit of 25%-33% effectiveness and the residual heat energy got by the burning cycle goes through the fumes and afterward into the environment. This prompts the expansion in discharge of unsafe gases which increments an unnatural weather change and other natural issues. This caused to grow the consideration on improving the productivity of internal combustion engines. For the utilization of waste heat from a vehicle exhaust our primary goal is Thermoelectric Generators (TEG). It is an exceptionally doped semiconductor strong state gadget, which changes over the heat on the fumes surface straightforwardly into electrical energy and this would permit a huge increment of the general ignition motor execution. The thermoelectric materials and the position of installation plays an important role in increasing the efficiency.

KEYWORDS: ICE (internal combustion engines), Ignition motor, TEG (Thermoelectric Generator), Heat recuperation, Waste heat recovery, Seebeck effect, Peltier effect, Thomson effect, Thermoelectric Module, Thermoelectric Materials, Efficiency.

Introduction

Thermoelectric Generator (TEG) is a strong state gadget, which changes over the heat energy accessible in a vehicle's fumes into electrical energy and it is then used to expand the exhibition of the vehicle. It is pointless to consider the expense of the heat energy contribution as it utilizes just the waste heat from the vehicle. High fuel expenses and reliance on unfamiliar oil have come about to invest amounts of energy on complex motor plans to diminish fuel utilization. The transformation proficiency of a TEG is around 5-8%. As it is a strong state gadget, number of turning and moving parts has been killed. Considered with highlights, that they produce no commotion and include no hurtful specialists.

TEGs are the most generally favored gadgets for squander heat recuperation. With the utilization of incredible measure of waste heat produced from an IC motor activity, valuable power age is conceivable. TEG wipes out emanation and because of its advantages, it tends to be considered as a promising elective green innovation. For improving the productivity of a TEG, the material utilized for the thermoelectric module assumes an indispensable job. TEGs utilized in vehicles for exhaust heat recuperation are Automotive Exhaust Thermoelectric Generators (AETEG).

TABLE 1
Abbreviations

TEG	Thermoelectric Generator
AETEG	Automotive Exhaust Thermoelectric Generator
IC	Internal Combustion
TE	Thermoelectric
Bi2Te3	Bismuth Telluride
PbTe	Lead Telluride
CaMnO	Orthorhombic Perovskite
Sb2Te3	Antimony Telluride
BMW	Bavarian Motor Works
GMC	General Motor Company

Principles of Working of TEG

Thermoelectric Generator shown in figure 1, is a device that converts the received heat energy directly into electrical energy. TEG works on the principle of Seebeck effect, Peltier effect and Thomson effect. In a Thermoelectric Generator electrical power generation is obtained by the p-n junction, which is made from a different material.

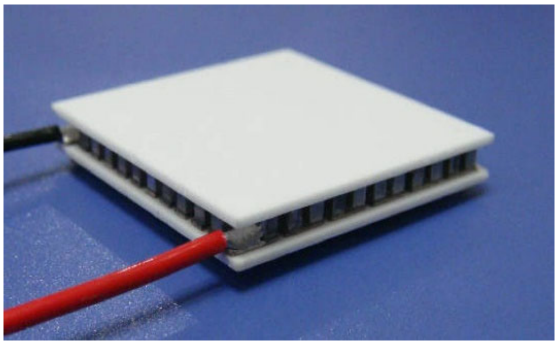

Fig. 1. Thermoelectric generator

A. **Seebeck Effect (Thermoelectric power generation):** It was found by Thomas Johann Seebeck in 1822. He found that if a temperature slope is put over the intersections of two different transmitters, then electrical flow would stream. Extent of voltage created is relied upon the sort of the leading material that is utilized and the produced voltage is corresponding to temperature distinction of the conductors. It is an exemplary case of an electromotive force(emf). The Seebeck effect is shown below in figure 2.

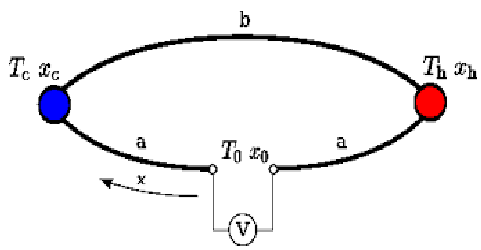

Fig. 2. Seebeck Effect

B. **Peltier Effect (Thermoelectric heating and cooling):** It was found by Jean Peltier in 1834. He found that going current through two unique conductors, makes heat be either radiated or consumed at the intersection of the materials. By retaining heat energy from cold intersection, electrons move from p-type to n-type. Here electrons stream from n-type to p-type material through electric connectors and gives the additional energy at the hot intersection. The Peltier effect is shown below in figure 3.

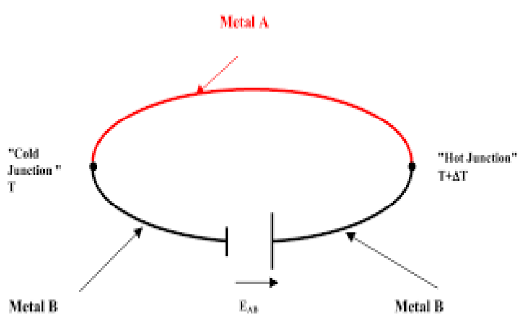

Fig. 3. Peltier Effect

C. **Thomson Effect:** It was found by William Thomson in 1855. He drew the association between the Seebeck and Peltier impacts. The heat power is retained or developed along the length of a material pole whose closures are at various temperatures. This heat is corresponding to the progression of current and to the temperature angle along the bar. The Thomson effect is shown in Figure 4.

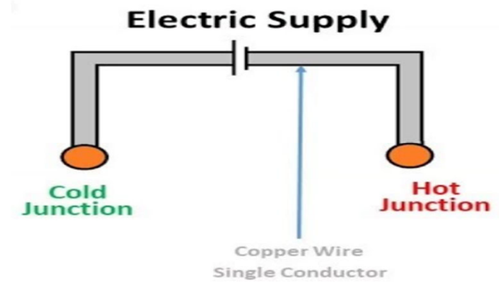

Fig. 4. Thomson Effect

Working of TEG

The electrical power generation in a Thermoelectric Generator is obtained by the p-n junction. AETEG consist of one hot side and one cold side as given in the figure 5.

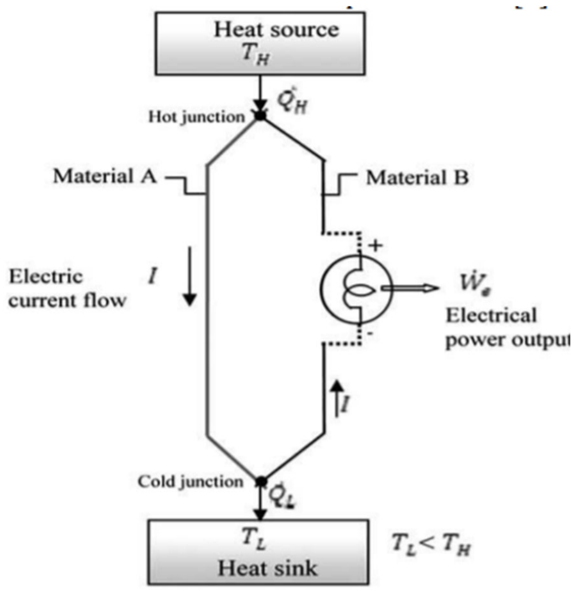

Fig. 5. Principle of thermoelectric generator

The part p of the p-n intersection incorporates openings however the part n incorporates electrons. The temperature contrasts over the p-n intersection permits the electrons and openings in p and n material to move from the heated side with elevated temperature to cooled side with dropped temperature because of the addition of waste heat, at that point it streams toward cold side to lose the energy and it falls in the hot side again to pick up the heat energy from the fumes of the vehicle. The cycle of increase and losing the heat energy permits the openings and electrons to move in a shut round movement. Along these lines inconsistent quantities of electrons need to cross the intersections and inconsistent voltages are created. Since there is a net voltage around the circle, a current will be delivered and this can be utilized to control a heap.

Figure of Merit

The exhibition of a material used for manufacturing thermoelectric gadget relies upon the estimation of its figure of merit (ZT) from which it is made of. It is given by,

$$ZT = \alpha^2 T/kR$$

α - Seebeck coefficient
k - Thermoelectric conductivity
R - Electrical resistivity
T – Temperature
Z - Figure of merit

Compatibility Factor

The rate of current density that amplifies the lowered efficiency is titled as compatibility factor. It is expressed as,

$$S = \frac{\sqrt{(1+zT)}}{\sigma T} - 1$$

Z - Figure of merit (μV/K)
T - Average temperature
σ - Seebeck coefficient (V/K)
u - Current density (A/m3)
S - Compatibility factor (1/V)

Advantages

- Non-conventional system.
- Small in size and easily portable.
- Capable of operating at high temperatures.
- Environment friendly.
- Requires less number of parts.
- Any electronic devices can be charged by the produced electricity.
- Charging time is less as temperature increases.
- Wide areas of application.
- Reduces transmission losses.
- Maintenance is low.
- Operation is quiet.

Limitations

- Design is complex.
- Uneven temperature distributions on the plate may cause inefficiencies.
- Requires relatively constant heat source.
- Low efficiency rate in energy conversion.
- Applications are limited.

Cost Considerations

Ordinarily utilized materials in TEG gadgets depend on Bi2Te3 and PbTe. Bi2Te3 at room temperature 9K as the cold side and Lead Telluride at 500K as the hot side. The thermoelectric characteristics of the two materials are determined by considering figure of merit. For a material to be a reasonable wellspring of conceivable power, it ought to have a figure of merit estimation of 2 to 3. Thermoelectric material must have a wide temperature inclination. In the event that a material doesn't have wide temperature inclination, it will encounter heat-incited pressure, which may prompt the crack of the material.

Among these materials, Bi2Te3 is regularly utilized, as different materials are costly components. The expense of thermoelectric materials relies upon the synthesis of the materials utilized. To diminish expenses and increment the business capacity of TEGs, improvement of oxide, silicide, polymer and tetrahedrite TE materials are finished. Better exhibitions can be accomplished by doping these materials. Figure 6 and 7 reveals the classification and price of TE materials by considering price of the elements and the raw materials used. Table 2 reveals the comparison of price for thermoelectric materials of pure and raw form.

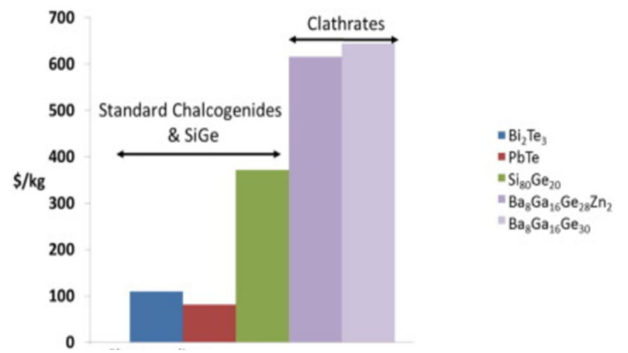

Fig. 6. Price of the material

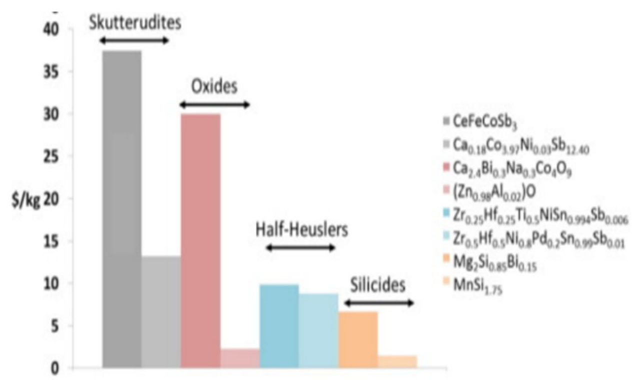

Fig. 7. Price of the material

TABLE 2

Comparison of pure and raw material price

Materials considered	*Material price($/kg)- Pure*	*Material price($/kg)- Raw*
Chalcogenide	807	110
SiGe	7082	372
Skutterudite	205	25
Half Heusler	531	12
Silicide	191	7
Oxide	51	2

Location of TEG in Automobiles

Execution of a Thermoelectric Generator (TEG) is likewise founded on its establishment area. The TEG can be introduced between the collector and the exhaust system on the fumes pipe. The generated heat from the exhaust is absorbed and converted directly into electricity by the use of TEG.

Fig. 8. Location of TEG in automobiles

In an experiment conducted, the TEG was installed on three different location of the exhaust pipe and the net performances were examined. The installation locations are:

1. The TEG is mounted at the tip of the exhaust system.
2. The TEG is mounted on top of the silencer and catalytic converter.
3. The TEG is mounted between the silencer and the catalytic converter.

From these three possibilities, location 3 was discovered to be more preferable than other two locations. In location 3, the face of the heat exchanger achieved an elevated temperature and the pressure reduction of silencer, catalytic converter and heat exchanger was reduced, which is in line with the requirements of the exhaust system.

Applications of TEG in Automobiles

- BMW Vision Efficient Dynamics Program (2009)
  BMW, the global chief in vehicle manufacturing dispatched the AETEG Program Vision Efficient Dynamics Program in the month of march 2009. They developed a new model of vehicle which includes a Thermoelectric Generator, based on Bi2Te3 materials, for production of electric power on board. The vehicle used was a BMW 530i and is given in the figure 9. The Energy production reached the level of 200 W when driving on the highway at a speed of 130 km/h. It claimed a rate of 0.4 for figure of merit.

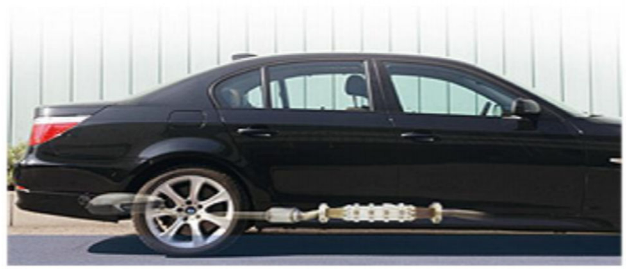

Fig. 9. BMW prototype vehicle

- RENAULT Heavy Duty Truck (2012)
  RENAULT implemented AETEG onto a truck diesel engine of 1L displacement producing 460hp and the arrangement generated an output of 1Kw. They focused on cheap, efficient and sustainable TE materials. The procedure was focused on material integration and scaling-up process. The target cost was 0.3-1.3$\$W_e$. The formation of NOx gases is also minimal. RENAULT Novel heat exchanger is shown in figure 10.

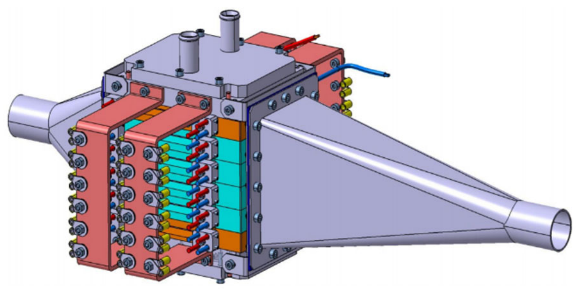

Fig. 10. RENAULT Novel Heat Exchanger

- GMC Sierra Pick-up Truck (2004)
  Clarkson University and associations, for instance, Hi-Z Technology, Delphi Harrison Thermal System and GM Powertrain Division dispatched an Automobile Exhaust Thermoelectric Generator venture in 2004. They examined the utilization of TEG onto a GMC Pickup Truck similarly as to build up a marketable strategy with the planned AETEG framework. The setup is given below in figure 11. It produced a maximum amount of 140W to 225W electricity.

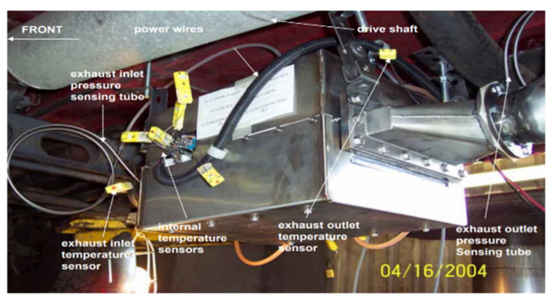

Fig. 11. GMC Pick-up Truck AETEG setup

Conclusion

- Recovery of waste heat allows capturing and reuse of exhaust heat created by internal combustion engines and their use for electrical work.
- With the use of TEG, electricity can be generated from the high temperature difference at low cost.
- Automobile industries are introducing TEG and looks forward to commercialize it.
- The performance of a TEG is based on change in vehicle speed, installation position and thermoelectric materials. The efficiency obtained from a TEG IS 5-8%.
- Bi2Te3 materials are commonly used for the manufacturing of TEG.
- Automobile industries are implementing TEG in the heavy-duty trucks, thereby minimizing the formation of NOx gases coming from the exhaust of the vehicle.

References

[1] A. Jacks delightus peter, Balaji.D, D. Gowrishankar Waste heat energy harvesting using thermo electric generator 1M. Tech AME, Hindustan University, Chennai 2Asst.Prof. Hindustan University, Chennai.

[2] A Venkatesh, A Nazar Ali, R Jaiganesh and V Indragandhi Assistant Professor, Department of EEE, Rajalakshmi Engineering College, Chennai, Tamilnadu, India. Extraction and conversion of exhaust heat from automobile engine in to electrical energy.

[3] Ankit Kumar Mishra, Ankit Kumar Singh, Ankur Prakash, Prof. R. S Ambekar Thermoelectric Generator B. Tech Electrical Engineering Bharati Vidyapeeth Deemed University Pune.

[4] Aravind satheesh, Magnus Philip, Rittomon Thomas Guided by-Mr Aju s Nair,Assistant proffessor of Electrical and Electronics Engineering Amal Jyothi College of Engineering, India Converting Waste Heat from Automobiles to Electrical Energy.

[5] E F Thacher, BT Helenbrook, M A Karri, and C J Richter Department of Mechanical and Aeronautical Engineering, Clarkson University, Potsdam, New York, USA Delphi Corporation, Lockport, New York, USA. Testing of an automobile exhaust thermoelectric generator in a light truck.

[6] Mohd.Quasim Khan, S Malarmannan, G Manikandaraja B.Tech Student, SRM Institute of Science and Technology, Chennai, Tamil Nadu quasimk5@gmail.com, Assistant Professor, SRM Institute of Science and Technology, Chennai, Tamil Nadu. Power generation from waste heat of vehicle exhaust using thermo electric generator.

[7] Murtdha S. Imran, and Hayder J. Kurji Kerbala University, Engineering College, Mechanical Engineering Department, Kerbala, Iraq. waste heat conversion in compression ignition engine to the electric power by using exhaust heat recovery system contained TEG.

[8] Raj Kuhite, Sahil Sheikh, Aniket Thakur, Chandrakant Bharre, Nilima Mankar Asst. professor, Dept. of Mechanical Engg., Govindrao Wanjari College of Engg. & Technology, Nagpur, India UG Student, Mechanical Engineer, Govindrao Wanjari College of Engg. & Technology, Nagpur, India.

[9] M.A. Karri, E.F. Thacher, B.T. Helenbrook Department of Mechanical and Aeronautical Engineering, PO Box 5725, Clarkson University, Potsdam, NY 13699, USA. Exhaust energy conversion by thermoelectric generator: Two case studies

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