# Experimental Investigation on Thermo-Electric Generator Used in Compression Ignition Engines

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**Abstract:** ***A probe into an experimental study to utilize heat losses in an engine through exhaust gases for increasing an overall efficiency of an automobile was attempted. About 35-45 % of total heat is being carried by exhaust gases in a compression ignition engine. Exhaustive studies are being performed to study on the utilization of this waste gasesy. Here an attempt is made to use a Thermo-electric generator for recharging a battery in an automobile. Both simulation and Experimental analysis are made to test performance of an engine due to assembly of thermo-electric generator. A heat exchanger was designed and fabricated to Compression Ignition engine for the purpose. Further, the performance characteristic of the thermo-electric generator consisting of thermo electric modules was studied in detail. Seebeck and Peltier effects are used to convert the thermal energy produced due to temperature gradient into electrical energy.***

**Keywords:** Compression Ignition engine, Thermo-electric generator, Triangular Heat exchanger, Seebeck effect, Peltier effect, Thermo-electric module.

## 1. Introduction

A probe into literature provides large number of analytical, numerical, empirical and semi-empirical works concerning the design of a heat exchange. A few of these studies are highlighted here. Ghorbanpour et.al [1] have considered a hollow circular shaft made from functionally graded piezoelectric material which is rotating about its own axis with a constant angular velocity. They mainly focused on boundary conditions and discussed about the electro-thermo-mechanical stress and the electric potential distributions of a hollow shaft.

An inverse design problem to determine the optimal variables for a three-dimensional Z-type compact parallel flow heat exchanger was studied by Cheng-Hung Huang and Chun-Hsien Wang [2]. In their study, they presented five different optimization design problems using Levenberg-Marquardt method and a general purpose commercial CFD to obtain the uniform tube flow rates.

Design, assembly and performance of thermo-electric (TE) power generator were studied by Samir Bensaid and Mauro Brignone [3]. They mainly focused on the material that is used for Thermo-electric Plates which increases the energy conversion efficiency. It also gives us the clear definition of Seebeck Effect.

Li- Ling Liao and Ming- Ji Dai [4] have probed into computer aided design and analysis of a conventional Thermo electric generator with experimental design considerations. It consists of 12 pairs of thermo electric pillars. They also studied the performance using Slope method and focused on recycling of energy.

Use of thermo electric modules is intended for high temperature applications were studied by Amirkoushyar Ziabari and Ephraim Suhir [5]. They performed FEA analysis of the module to reduce the interfacial shearing stress and thermal stresses. A comparison between the Analytical and FEA analysis was shown.

Present research studies on the deposition of electrical conductive coatings on aluminium matrix composites that have been studied by A. Urena and M. V. Utrilla [6] consists of 75 Volume % of SiC particles to be used for electronics packaging.

M. Hatam et al. [7] who have presented a short review of heat recovery technologies in engines using heat exchangers. They presented that, in the most of the heat recovery technologies (ORC, TEG, EGR, HEXs and turbo- charging), the heat exchangers have an important role to transfer heat for recovering process. They said that a suitable design of a heat exchanger should be applied in accordance application. They stated that, if pressure drop is in an allowable limit, then the heat transfer increases. They also presented some of the experimental and numerical researches of heat exchanger designs used.

A rectangular Micro-channel method was presented by Sandip K.et al. [8] for a counter flow heat exchangers. They adopted methodology based on two methods, one being the one-dimensional model and the other being the CFD model. They compared both one dimensional and more accurate CFD models. They further provided a quantitative data for the optimal plate dimensions and resulting maximum power density.

New techniques to produce metal matrix composites by injecting silicon carbide particles into molten aluminium which is known as centrifugal atomization were given by Morteza Eslmian et al.[9] They explained the experimental procedure for this process with its composition.

Samir Bensaid and Mauro Brignone [10] have studied the design, assembly and performance of thermo-electric (TE) power generator. They mainly focused on the material that is used for Thermo-electric Plates which increases the energy conversion efficiency. There they have given the clear definition of Seebeck Effect.

## 2. Fabrication of Experimental Setup

Conversion of thermal to electrical energy directly without the intermediate step of kinetic energy gives an alternative method to produce high potential energy. The significance of thermo-electric converters led to improvements in material sciences and the progress of nanotechnology. The efficiency of thermoelectric converters in general, depends on material parameters. Furthermore, design aspects, especially the leg length and heat transfer conditions have a significant influence on power output and an efficiency. The focus of his work was the development of tools for the evaluation of thermoelectric power generation. The heat exchanger model was prepared in CATIA and the analysis has been done.

Figure 1 and 2 shows the simulation and fabricated models of a heat exchanger designed for the purpose to conduct the experiment for the purpose. Heat exchanger is designed in such a way that it results in maximum output voltage. In order to achieve this, number of shapes was experimented like cubical, parallelepiped, cylindrical and finally a triangular prism shaped Thermo-Electric Generator (TEG) was found to be appropriate for this particular application. Care has been taken to enhance the heat transfer rate by selecting the appropriate size of a heat exchanger so that the heat losses can be minimized.

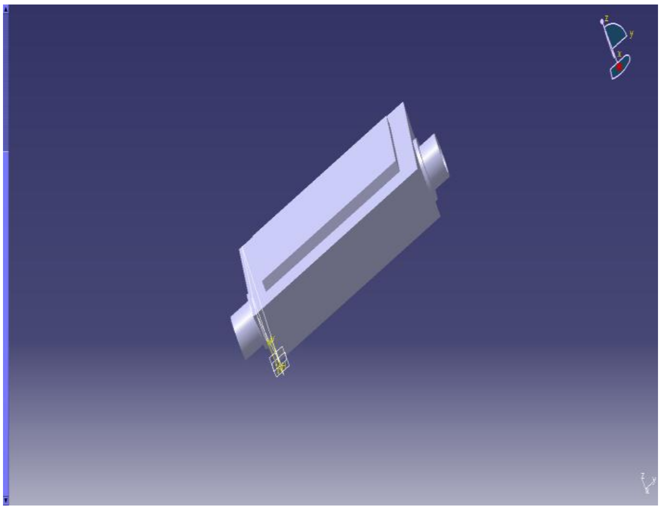

**Figure 1:** Simulation model of a heat exchanger fabricated for the purpose

The Thermo-electric generator consists of counter flow heat exchanger six Thermo-electric modules connected in two rows, three in each row with a with a cooling chamber as shown in Fig. 3. The heat transfer from the inner wall to the hot surface of the Thermo-electric module is basically due to conduction mode of heat transfer. Thermal resistance exists between the surfaces of the hot plate and Thermo-Electric Module (TEM) because of the surface roughness. Hence, care has been taken to ensure high degree of smoothness between the surfaces by polishing it. The most common materials used in the construction of the support structure of the TEG are steel, stainless steel. Construction of the support structure of the TEG by ferritic stainless steel was proposed to use in this study. The properties of this steel are discussed below.

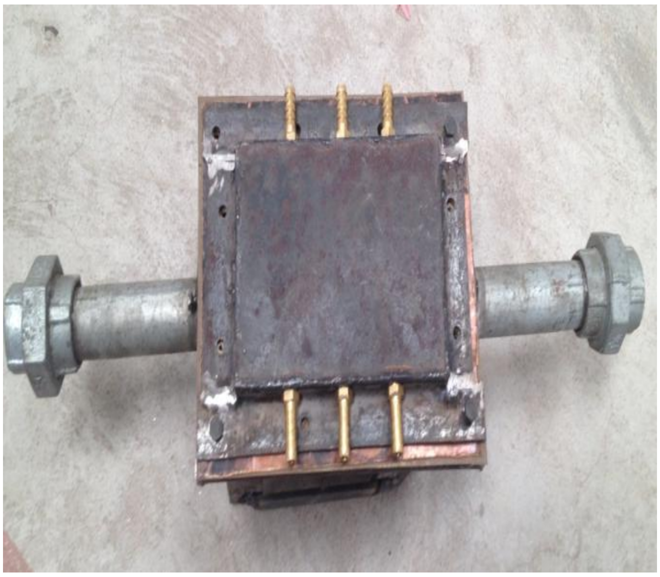

**Figure 2:** Fabricated model of a heat exchanger fabricated for the purpose

Two plates will be used for the fabrication of TEM viz., hot plate made of aluminium and cold plate made of copper. Modules are placed in between the hot plate and the cold plate. The exhaust gases comes in direct contact with the bottom side of the plate while the water on the top side of the plate. Here, aluminium plate is made up of 5 mm thickness while the copper plate is of 3 mm thickness.

Figure 4 shows the assembly of Thermo-electric generator to a four stroke single cylinder diesel engine with brake drum dynamometer is used for testing the performance of TEG. Care has been taken to allow the water to flow continuously in order to maintain the constant temperature in the cooling chamber so that uniform heat will be carried away by water on the upper portion of a heat exchanger. Exhaust gases flows through the lower portion of the heat exchanger as the gases comes in contact with the plate and the heat is transferred to modules via aluminium plate. Table 1 shows the engine specifications used for the experimentation. The performance tests have been conducted both before and after assembling the TEG to a compression ignition engine to observe the effect of engine parameters. It is observed that there is no effect on the parameters due to installation of heat exchanger.

It is required to raise the temperature difference on cooling and heating sides of the TEG to increase the production of electrical energy. Hence an appropriate design of a heat exchanger has become a criterion to increase the heat transfer rate. Weight and space plays an important role in design of a heat exchanger. Hexagonal, rectangular and triangular shaped heat exchangers were analyzed for experimentation. It is found that the triangular shaped heat exchanger is appropriate to use as it has minimum number of edges and smaller in size with maximum heat transfer rate. A rectangular cooling chamber was selected to produce cooling effect on other side of the module. This will enhance the temperature difference on two sides of the modules.

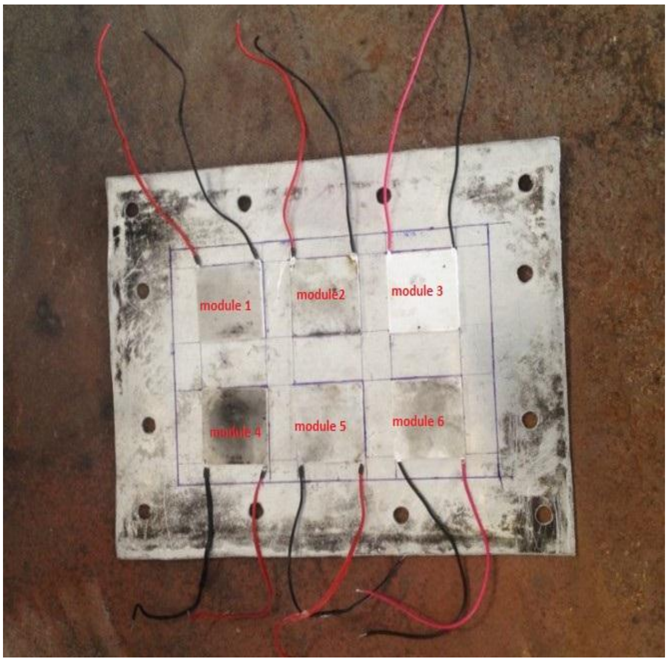


**Figure 3:** Selected location of modules on a aluminium plate

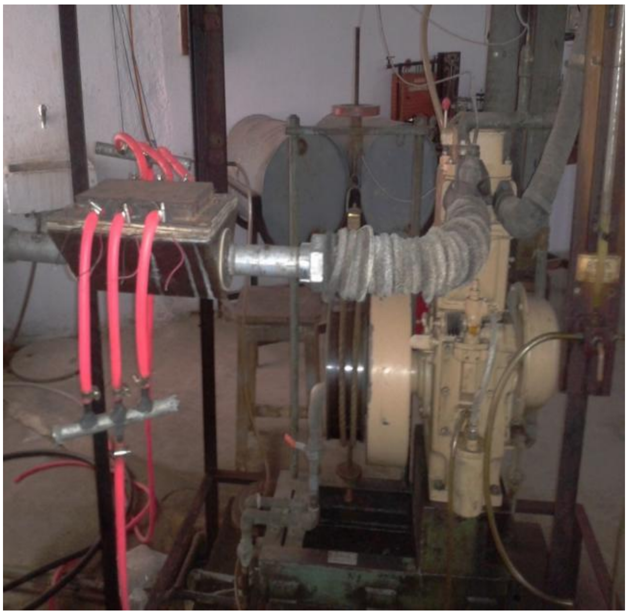

**Figure 4:** Assembly of TEG to a Compression Ignition engine.

The electricity required for continuous charging of battery used in automobiles is found to be around 12 volts, which is to be generated by these thermoelectric modules. Dynamometer torque, engine speed, TEG output, TEG coolant inlet and exit and surface temperatures were measured. The engine was operated at various loads using eddy current dynamometer. Engine load was varied by changing the engine speed keeping the torque constant. Horiba exhaust gas analyzer was used to measure the exhaust gas toxicity. To achieve higher exhaust gas temperature the thermoelectric generator was located just down- stream of the exhaust headers next to catalytic converter. The only concern is that the generator, if located upstream of the catalytic converter, would decrease the efficiency and increase the warming time of the catalytic converters.

A test was carried out on a four stroke single cylinder diesel engine with brake drum dynamometer without any modifications performed on it. The exhaust pipe was insulated on the upstream side of the exhaust chamber up to the catalytic converter to minimize heat loss. 0-1200°CK-type thermocouples with digital measuring unit was used to measure exhaust gas temperature on hot and cold side of TEM. Back pressure of the Exhaust gas was measured using a U- tube mercury manometer. D. C. voltmeter was used to measure the voltage produced by the TEG. A rotameter, was used to find the water flow rate through engine and cooling chamber. An additional coolant circuit (by-pass) was provided for TEG using solenoid valve in order to overcome the burn out of the TEM during the engine warm up period.

## 3. Results and Discussion

A study has been performed to test the performance of modules used in TEG. Some of the results have been presented for the purpose.

**Table 1:** Specifications of a Compression Ignition Engine

| *Item* | *Details* |
|---|---|
| Type | Single cylinder Four stroke vertical water cooled diesel engine. |
| Bore (D): | 80 mm |
| Stroke length (L) | 110 mm |
| Compression ratio | 16.1 |
| Rated power (BP) | 3.68 KW at 1500 rpm |
| Rated speed (N) | 1500 rpm |
| Mechanical dynamometer (Rope brake) | Drum diameter ($d_d$): 3000 mm<br>Rope diameter ($d_r$): 15 mm<br>Effective radius ($R_e$) = $d_d$ + $d_r$/2 = 157.5 mm =0.1557 m<br>(i) Dead weights for loading the engine in kg.<br>(ii) Hand Tachometer for measuring speed in rpm<br>(iii) Orifice meter in Conjunction with. U-Tube manometer for measuring volume flow rate of air ($m^3$/Sec). |

Exhaustive studies were performed to check the effect of assembly of TEG on engine. As an example, a study is performed on the effect of mechanical efficiency of a four stroke single cylinder diesel engine with brake drum dynamometer with applied load for two different cases is presented in Fig. 5. Curve 1 shows the case of variation of mechanical efficiency before assembling of TEG voltage with the application load on an engine while the curve 2 shows the variation of mechanical efficiency after assembling TEG. We can observe that there is almost no effect on the engine due to assembly of TEG.

Figure 6 shows the variation of voltage with the application load on an engine for three different modules 1, 2, 3. The location of modules on the aluminium plate was shown in Fig. 2. It is observed that for a given module as the load or brake power increases the voltage increases and reaches maximum. Also, for a given load the voltage is in module 1 is more than that of for module 2 and 3 because it is placed nearer to the heat exchanger than that of module 2 and 3.

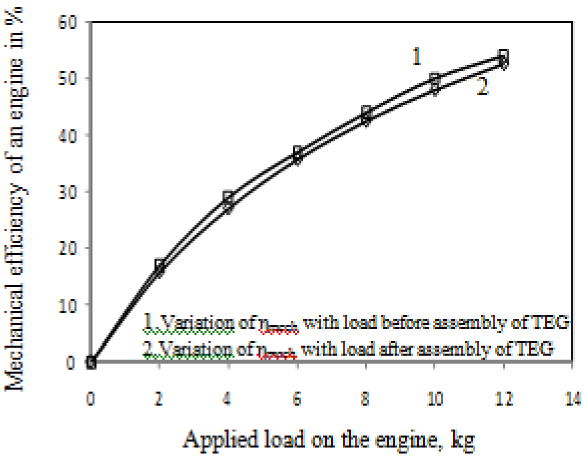


**Figure 5:** Variation of mechanical efficiency with applied load

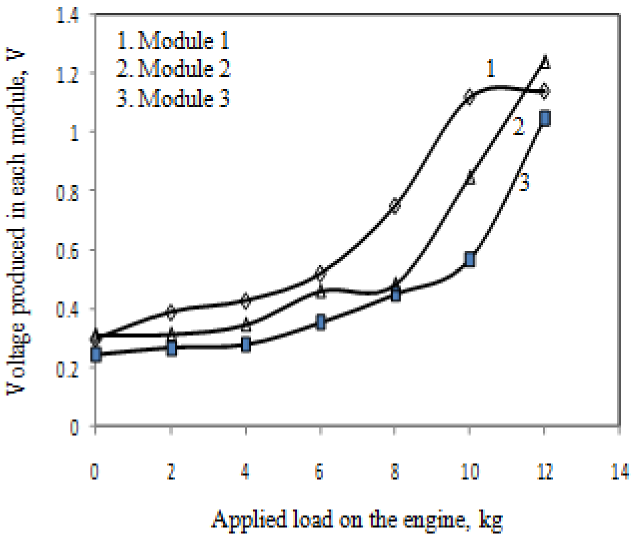


**Figure 6:** Variation of voltage with applied load for modules 1, 2, 3

The variation of voltage with applied load in modules 4, 5 and 6 is shown in Fig. 6. Here too we can observe that for a given module as the load or brake power increases the voltage increases and reaches maximum. Also, for a given load the voltage is maximum for module 4 than that of for module 5 and 6. Also we can observe that the voltage is more in module six at maximum load than that of module 5. This is obvious because as we move at the end location the temperature difference between the water and exhaust gases increases.

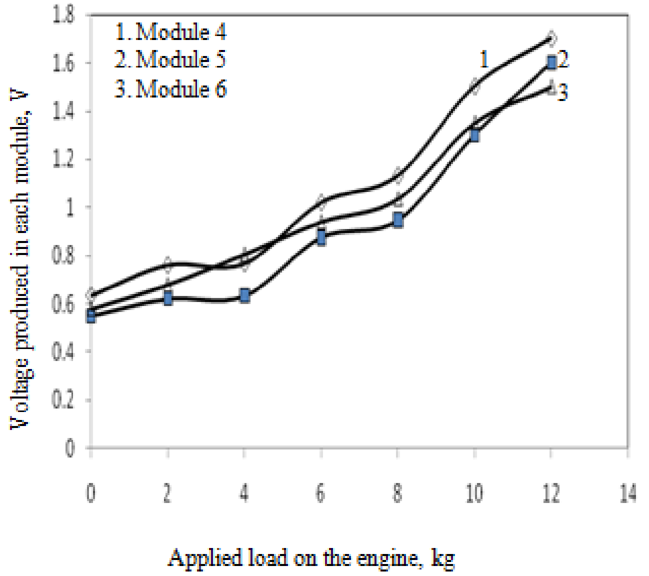


**Figure 7:** Variation of voltage with applied load for modules 4, 5, 6

## 4. Conclusion

A detailed study was performed to discuss performance of thermo-electric generator modules used in Compression Ignition engines for production of an electrical energy. Exhaustive studies were presented to show that the assembly of TEG module have no effect on the performance of an engine.

## References

[1] A. Ghorbanpour Arani, R. Kolahchi, A. A. Mosallaie Barzoki, "Effect of Material in - Homogeneity on Electro-Thermo-Mechanical behaviors of functionally graded Piezoelectric Rotating Shaft", Journal of Applied Mathematical Modelling, Vol. 35, Nov 2010, ISSN:2771-2789.

[2] Cheng-Hung Huang, Chun-Hsien Wang, "The Design Of Uniform Flow Raesfor Z-type Compact Parallel Flow Heat Exchangers", International Journal of Heat and Mass transfer, Vol.57, Oct 2012, ISSN:608- 622.

[3] Amirkoushyar Ziabari , Ephraim Suhir , Ali Shakouri , 'Minimizing Thermally Induced Interfacial Shearing Stress In a Thermoelectric Module with Low Fractional Area Coverage" , Journal Of Microelectronics , Vol.45, Dec 2013, ISSN: 547- 553.

[4] Li- Ling Liao, Ming- Ji- Dai, Chun-Kai- Liu, Kuo- Ning Chiang, "Thermo-Electric Finite Element Analysis and Characteristic Of Thermoelectric Generator With Intermetallic Compound", International Journal of Microelectronic Engineering, Vol.120, Oct 2013, ISSN: 194- 199.

[5] Amirkoushyar Ziabari , Ephraim Suhir , Ali Shakouri , 'Minimizing Thermally Induced Interfacial Shearing Stress In a Thermoelectric Module with Low Fractional Area Coverage" , Journal Of Microelectronics , Vol.45, Dec 2013, ISSN: 547- 553.

[6] A.Urena, M.V.Utrilla, "Electroless Multilayer Coatings on Aluminium- Silicon Carbide Composites for

Electronics Packaging, Journal Of European Society", Vol. 27, 2007, ISSN: 3983-3986.
[7] M. Hatami, D. D. Ganji, M. Gorji-Bandpy, "A Review of different Heat Exchangers Designs for Increasing the Diesel Exhaust Waste Heat Recovery", Journal of Renewable and Sustainable Energy Reviews, Vol. 37, may 2014, ISSN: 168- 181.
[8] Sandip K. Saha, Martine Baelmans, "A Design Method for Rectangular Microchannel Counter Flow Heat Exchangers", International Journal of Heat and Mass transfer, Vol.74, Feb 2014, ISSN: 1- 12
[9] Morteza Eslamian , Joel Rak , Nasser Ashgriz , "Preparation Of Aluminium/ Silicon Carbide Metal Matrix Composites Using Centrifugal Automization" Journal Of Powder Technology , Vol.184 , July 2007, ISSN: 11-20.
[10] Samir Bensaid, Mauro Brignone, Alessandro Ziggioi, "High Efficiency Thermo- Electric Power Generator", International Journal of Hydrogen Energy, Vol.37, Sep 2011, ISSN: 1385- 1398.

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