Experimental investigation on Waste recovery from Compression Ignition Engine Using Thermo-Electric Generator (TEG)

G. Ganesh Kumar

***Abstract*— Some important results of experimental investigation on recovery of waste gases are provided here. The major part of the heat supplied in a compression ignition engine was due to exhaust gases. Hence an attempt is made to use this waste for production of electrical energy to charge the battery used in automobiles i.e., the unavailable energy is used to convert into usable energy . This leads to increase the overall efficiency of a engine. Literature reveals that approximately 35% of the heat is wasted through exhaust gases. Hence an experimental set-up of Thermo-Electric Generator (TEG) comprising thermo-electric modules is designed and fabricated to convert this thermal energy to electrical energy. Care has been taken while assembling the Thermo-electric generator so that there is no effect on the performance of an engine. Further, the performance characteristics of the thermo-electric generator consisting of thermo electric modules were studied. The thermal energy from temperature gradient is converted into electrical energy by using the working principle of Seebeck and Peltier Effects.**

***Index Terms* — Seebeck effect, Peltier effect, Thermo-electric module. Waste Heat Recovery, Compression Ignition Engine,**

I. LITERATURE REVIEW

A Thermo-electric Generator was designed and fabricated to study the performance characteristics of TEG modules for a Compression Ignition engine.

Literature reveals exhaustive number of methods to design a heat exchanger based on application. Selection of the appropriate design of the TEG is done based on literature study. A low weight and cost is taken as a design criteria.

The credit goes to Samir Bensaid and Mauro Brignone [1] 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.

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.

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. [3] They explained the experimental procedure for this process with its composition.

A rectangular Micro-channel method was presented by Sandip K.et al. [4] 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.

Ghorbanpour et.al [5] 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 that which results in material homogeneity.

A short review of heat recovery technologies in engines using heat exchangers was presented by Hatam et al. [6] 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.

The Computer Aided Design and Analysis of a conventional Thermo electric generator with experimental design considerations was studied by Li- Ling Liao and

***Manuscript received May, 2015*.**

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ISSN: 2278 – 7798

Ming-Ji Dai [7]. They studied its performance using Slope method and they mainly focused on recycling of energy.

Amirkoushyar Ziabari and Ephraim Suhir [8] have described about the thermo electric modules which are intended for high temperature applications. They have also performed FEA analysis of the module to reduce the interfacial shearing stress and thermal stresses.

II. INTRODUCTION

The recovery of exhaust gases from compression ignition engine were utilized by using the principle of Peltier and Seebeck effects to convert thermal energy due to temperature gradient into electrical energy to recharge the battery in the automobile. Direct thermal to electrical energy conversion, without the intermediate step of kinetic energy i.e., with no moving parts gives an alternative method to produce high potential energy. The improvements in material sciences and the progress of nanotechnology bring thermoelectric materials and therefore thermo electric converters to renewed significance. The efficiency of thermoelectric converters in general, depends on material parameters. Furthermore, design aspect especially the heat transfer conditions have a significant influence on power output and an efficiency. The focus of this 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 shows the simulated model of heat exchanger designed while Fig. 2 shows the experimental model of heat exchanger for TEG to conduct the experiment. Heat exchanger is designed in such a way that it results in maximum output voltage. In order to achieve this, number of shapes were experimented viz., cubical, parallelepiped, cylindrical, triangular, etc. Finally it was found that a triangular prismatic 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.

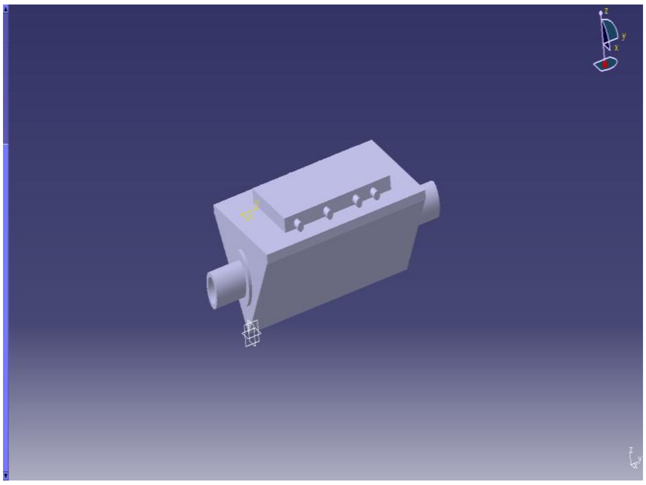

Fig. 1 Simulated model of a heat exchanger
Fabricated for the purpose

III. EXPERIMENTAL SET-UP

A counter flow with a cooling chamber type heat exchanger was selected for conduction of experiment on four stroke single cylinder diesel engine using TEG setup consisting six Thermo-electric modules connected in two rows, three in each row as shown in Fig. 2. 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.

Fig. 2 Simulated 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

ISSN: 2278 – 7798

plate. Here, aluminium plate is made up of 5 mm thickness while the copper plate is of 3 mm thickness.

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 is shown in Fig. 4. 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.

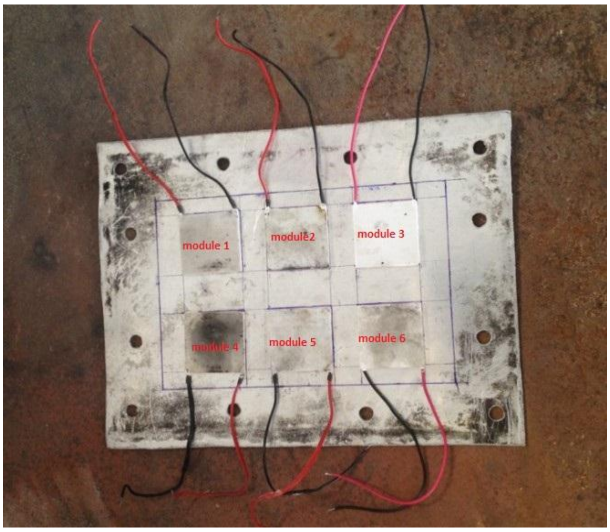

Fig. 3 Fabricated model of a heat exchanger fabricated for the purpose

In order to raise the temperature gradient for increasing the efficiency of a heat exchanger to produce more electrical energy, the water temperature is maintained lower. It has become a criteria to select an appropriate design of a heat exchanger for raise in power output. Hence, weight and space are the two parameters that are considered during design of a heat exchanger. Hexagonal, cubical, 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.

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.

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 Rope diameter (d_r): 15 mm Effective radius (R_e) = d_d + d_r/2 = 157.5 mm =0.1557 m (i) Dead weights for loading the engine in kg. (ii) Hand Tachometer for measuring speed in rpm (iii) Orifice meter in Conjunction with. U-Tube manometer for measuring volume flow rate of air (m^3/Sec).

ISSN: 2278 – 7798

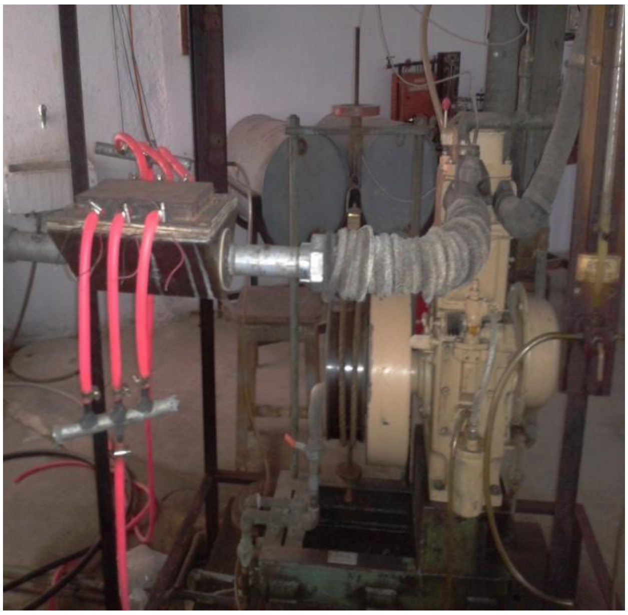

Fig. 4 Assembly of TEG to a Compression Ignition engine.

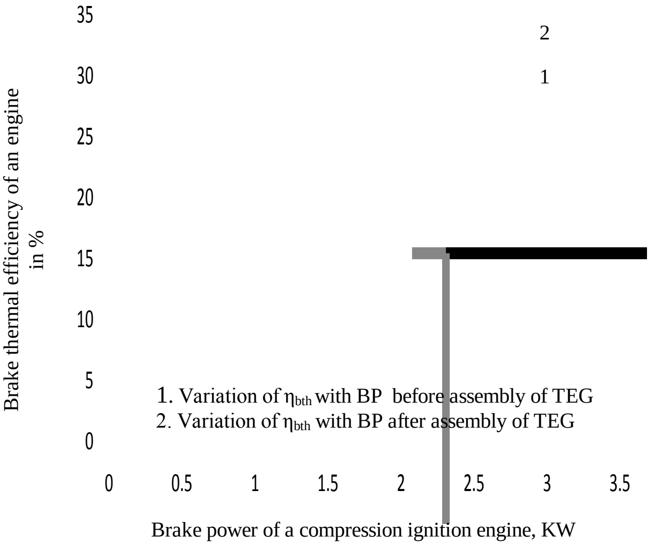

Fig. 5 Variation of mechanical efficiency with brake power before and after assembly of a TEG

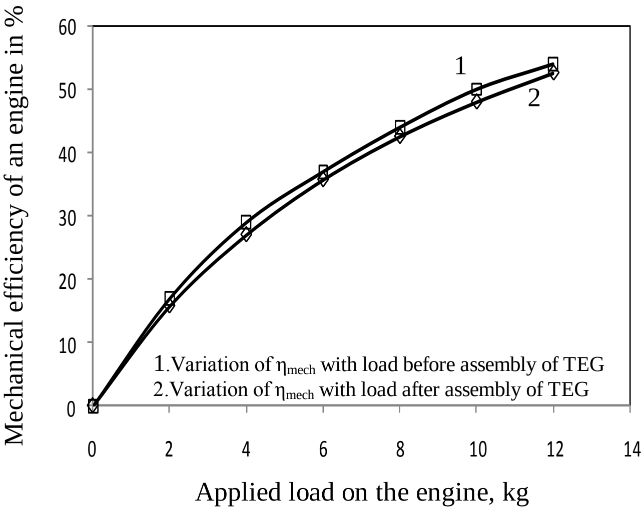

Fig. 6 Variation of mechanical efficiency with applied load

IV. 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.

To check the effect of assembly of TEG on engine performance test was conducted before and after the assembling of TEG setup on a CI engine. Here, some studies are presented to show that there is no change in the performance. As an first illustration, the effect of brake thermal efficiency and indicated thermal efficiency were shown in the Fig. 5. It can be seen that the performance of an engine is almost same and have no effect due to installation of TEG.

Similarly Fig. 6 shows the effect of mechanical efficiency of a four stroke single cylinder diesel engine with brake drum dynamometer with Brake power.

For both the cases Curve 1 shows the case of variation of before assembling of TEG voltage with Brake power and curve 2 shows the variation of mechanical efficiency after assembling TEG.

Figure 7 shows the variation of voltage with the application load on an engine for six different modules. The location of modules on the aluminium plate were shown in Fig. 2. It can be seen that for a given module as the load or 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 to 6. This is because it is placed nearer to the heat exchanger than that of module 2 and 3.

ISSN: 2278 – 7798

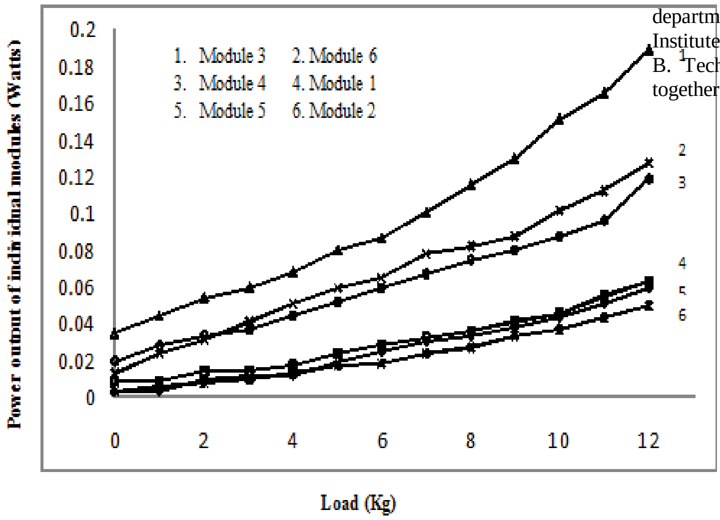

Fig. 7 Variation of mechanical efficiency with brake power before and after assembly of a TEG

V. CONCLUSION

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

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ISSN: 2278 – 7798