THERMO ELECTRIC POWER GENERATION USING HEAT FROM EXHAUST GAS – A RECENT REVIEW

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ABSTRACT

   Today world is under pressure to produce energy that would affect environment to a minimum level. As it is aware that world is under energy crisis, so there is a need for development of a novel technology to generate energy that would affect environment to a minimum level. One such novel technology would be thermo electric power generation. This paper aims to review the possibilities of generating power using Thermo Electric Generator (TEG). Through this review it can be concluded that thermo electric generators can be used in automobiles to generate power effectively for different systems. The best part of thermo electric generator is that exhaust gas heat can be utilized to generate power.

   Keywords – *Automobiles, Energy Crisis, Exhaust gas heat, Novel technology, Thermo Electric Generator*

I. INTRODUCTION

   Thermo electric generator converts thermal energy into electrical energy. This conversion takes place based on seebeck effect. A thermoelectric generator (TEG) generates voltage because of charge carriers in semiconductor pins, which are free to move much like gas molecules while carrying charge as well as heat. A potential difference is produced because of the buildup of charge carriers, which result in net charge at the cold end. Since TEG does not have any moving part and there is no combustion so they can be considered as one of the alternative renewable energy resources. TEG may be utilized to recover waste heat and convert it into electrical power, which becomes important with awareness of the environmental impact on global climate change.
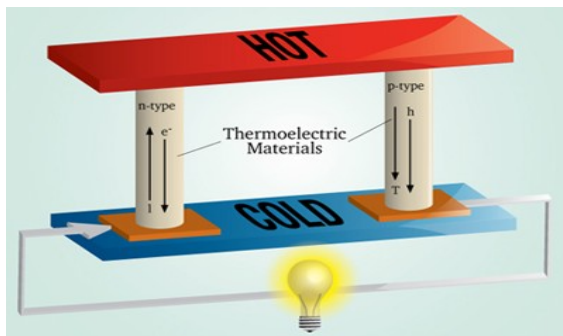

Fig. 1. *Thermo Electric Power Generation*

   Present paper aims to review the possibilities of thermoelectric power generation in automobiles. As most of the energy that is generated in automobile engine gets wasted, so if a thermo electric generator which works on automobile exhaust gas heat is incorporated in a automobile would increase the efficiency of the engine. The energy that is generated using a thermo electric power generator can be used to run air conditioning unit of automobile and it act as a power source to electrical system of the automobile.

II. REVIEW ON THERMO-ELECTRIC POWER GENERATION

  Case study was done on an individual module test system to test and analyze the impact of thermal imbalance of a TEG on the output electrical power. Variability of the temperature differences and pressure were also tested.

  It can be concluded that a proper mechanical pressure applied on the module improves the electrical performance. The maximum output power rises to 17.3W, 22.5% more than the power generated by the TEG without thermal insulation, when the engine operates at 3400 rpm. [1]

  The results reflect that heat absorbed, power output, and conversion efficiency increase significantly with increase in heat transfer coefficient up to 400 $Wm^2 K^{-1}$. The power output and conversion efficiency of a two-stage TEG is found to be higher than that of the single-stage TEG when the temperature of heat source is varied from 600 K - 800 K. [2]

   Low-temperature thermoelectric material (semi-conductor) bismuth telluride and medium-temperature thermoelectric material (semiconductor) skutterudite are employed in the working models instead of conventional materials and the exhaust gas of internal combustion engine is utilized as heat source.

  The results indicate that the heat source temperature plays a pivot role in design of a thermoelectric generator when the heat transfer coefficient is more than 400 W/m^2 K. The performance of the single-stage thermoelectric generator of thermo electric material bismuth telluride is better material than those of the two stage thermoelectric generator when the heat source temperature is maintained less than 600 K. [3]. The performance variation of TEGs becomes more significant with faster/sudden acceleration or declaration.

  The transient response of the hot and cold side temperatures, voltage and power in deceleration is less significant than acceleration. A higher road grade can increase the power output of TEG significantly, and lead to a faster transient response. The results suggest that a highly frequent change of driving condition may have a negative effect on the TEG performance.
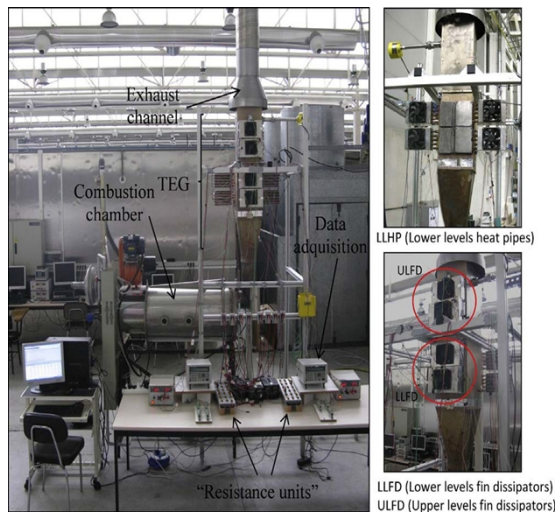
Fig. 2. *TEG prototype at the exhaust of the combustion chamber*

It is found that the vehicle speed has a pivot role in affecting the TEG performance for waste heat recovery, the higher the vehicle speed; the better would be TEG performance. The maximum power output is 18W at 20 km h⁻¹, and it reaches 220W at 120 km h⁻¹. [4]

A thermoelectric generator prototype has been built; it produces 21.56W of net power, taking into account of difference between the produced thermoelectric power and consumption of the auxiliary equipment, using an area of 0.25 m² (approximately 100 W/m²). [5]

A plate-shaped heat exchanger with chaos-shaped internal structure and thickness of 5 mm was tested and it attains a relatively ideal (high) thermal performance, which is practically useful to enhance the thermal performance of the TEG. [6]

Smaller inlet of exhaust channel increases the heat transfer to TEG modules, but increases the flow resistance, and therefore a moderate channel size can be employed. Based on the design and operating conditions in the present study, an exhaust channel with cross section of 60 mm x 40 mm would be optimum to balance the flow resistance and TEG power output. [7]

Six different exhaust heat exchangers were studied and designed within the same shell, and their computational fluid dynamics (CFD) models were developed using software package to compare heat transfer and pressure drop in typical driving cycles for a vehicle with a 1200 L gasoline engine. Serial plate structure enhanced heat transfer by 7 baffles and transferred the maximum heat of 1737 W. It also produced a maximum pressure drop of 9.7 KPa in a suburban driving cycle. [8]

Plate-shaped heat exchanger made of brass with accordion shaped internal structure achieves a relatively ideal performance, which can practically improve overall thermal performance of the TEG.

A heat exchanger made of brass with accordion shape and surface area (660mmx305mm) is selected for the hot section .It can reduce the

thermal resistance and obtain a relatively high surface temperature and uniform temperature distribution to improve the efficiency of the TEG. [9]

For the different start-up modes conditions, the current would be the driving factor determining the heat flow and heat generation. With the increased currents, the temperature differences generated across the hot and cold junctions reduce due to the enhanced Peltier effect. With differential start-up currents, the durations to obtain steady-state power are similar (the difference is less than 5.2%). However, the durations required to reach 40% and 80% of steady-state power are significantly affected by the start-up current. [10]

The power generation was greatest when a rectangular pillar heat sink was used, followed by a triangular prism heat sink installed to face the direction of the exhaust flow; the least power was generated when the heat sink used was a triangular prism heat sink installed to face the reverse direction of the exhaust gas flow.

Under each experimental condition, increasing the engine load increased the differential pressures at both ends of the thermoelectric module. The lowest differential pressure was observed from the triangular prism heat sink installed in the reverse direction of exhaust gas flow, followed by the forward-facing triangular prism heat sink. Among the experimental conditions, the greatest differential pressure was recorded for the rectangular pillar heat sink.

The performance of the thermoelectric modules increased as the temperature of the hot side was increased, until the durable temperature of the thermoelectric module was exceeded. So, temperature difference between the two ends of the thermoelectric module and the differential pressure of the exhaust gas are the key factors in the module's power generation performance. [11]
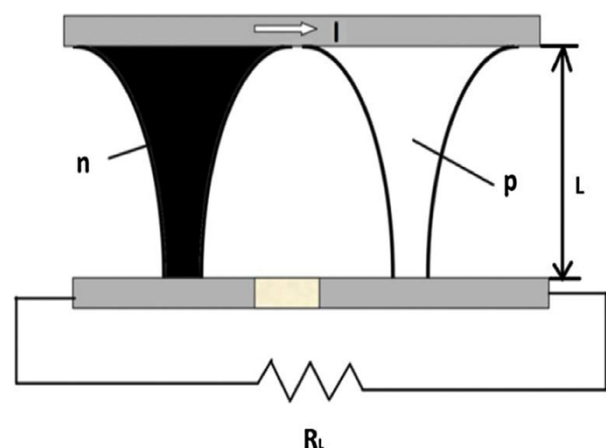

Fig. 3. *A schematic view of TEG with variable cross section legs*

The effect of pin leg geometry on thermal performance of the device is formulated thermo-dynamically. In this case, the exponential area variation of pin legs is considered and dimensionless geometric parameter 'a' is introduced in analysis.

It is found that increasing dimensionless geometric parameter improves the thermal efficiency of

the device; however, the point of maximum efficiency does not coincide with the point of the maximum device output power. It is found that geometric leg parameter influence significantly device thermal efficiency which is more pronounced with external load ratio (RL/Ro). Increasing external load ratio enhances thermal efficiency of the thermoelectric generator; in which case, varying external load ratio modifies the value of corresponding geometric leg parameter for the maximum thermal efficiency. Thermoelectric device parallel pin geometry (a = 0) results in the maximum thermal efficiency for low values of external load ratio. As the external load ratio increases, the corresponding leg geometric parameter becomes a > 0 or a < 0 for the maximum thermal efficiency. [12]

It can be proposed that a segmented thermoelectric generator (TEG) recover exhaust waste heat from a diesel engine (DE) efficiently. The results conclude that segmented TEG would be more suitable than traditional TEG for a high-temperature heat source. The maximum output power increased with a decrease in the thermocouple length; however, the maximum conversion efficiency decreased with an increase in the thermocouple length. [13]

Major issues to resolve for TEG commercialization are material selection based on average ZT, material thermal and chemical stability, and optimization of hot and cold side thermal resistances (e.g. heat exchangers). Moreover, the manufacturability of thermoelectric devices combined with the total system cost will influence the technology's market, readiness of product supply, and cost competitiveness. [14]

An innovative design of open-cell metal foam-filled plate heat exchanger based thermoelectric generator system (HE- TEG) was developed to utilize low grade waste heat. High heat exchanger efficiency of 83.56% between heated air and cold water was achieved. [15]

There are chances of compatibility problems among TEG, CC (catalytic converter) and muf (muffler). So varied installation position of TEG was proposed and proposed three different cases as follows,

Case 1: TEG is located at the end of the exhaust system;
Case 2: TEG is located between CC and muf;
Case 3: TEG is located upstream of CC and muf.

Simulations and experiments were initiated to compare different characteristics (thermal uniformity and pressure drop) over the above said three operating cases. From the results from the simulation and experiment, heat exchanger in case 2 found to be most efficient. [16]

A thermoelectric module consists of thermoelectric generator and a cooling system was prototyped to improve the efficiency of an IC engine. To apply this module, two potential positions over the automobile were chosen. [17].

A novel prototype for two-stage TEG from

vehicle exhaust heat has been proposed. Outcomes show that a TEG module can generate a maximum power output of 250 W when operating at hot temperature of 473 K. [18]

This study emphasizes more on the vehicle exhaust potential using a RC (Rankine cycle). Analysis was carried out thermodynamically for water, R123 and R245fa and it was found that water as the working fluid has more advantages in applications of thermal recovery from exhaust gases of vehicles equipped with a spark-ignition engine. [19]

The electrical characterization of TEGs for constant-heat is studied and it investigates the relationship between maximum power point and open-circuit voltage. Work provides an insight on the optimization of the pellets geometrical parameter in order to increase the power that is to be generated. [20]

In this research, a multi objective optimization based on Artificial Neural Network (ANN) and Genetic Algorithm (GA) are applied on the obtained results from numerical outcomes for a finned-tube heat exchanger (HEX) in diesel exhaust heat recovery. Thirty heat exchangers with different fin length, thickness and fin numbers are modeled and those results in three engine loads are optimized with weight functions for pressure drop, recovered heat and HEX weight. Finally, two cases of HEXs (an optimized and a non- optimized) are produced experimentally and mounted on the exhaust of an OM314 diesel engine to compare their results in heat and exergy recovery.

All experiments are done for five engine loads (0%, 20%, 40%, 60% and 80% of full load) and four water mass flow rates (50, 40, 30 and 20 g/s). Results show that maximum exergy recovers occurs in high engine loads and optimized HEX with 10 fins have averagely 8% second law efficiency in exergy recovery. [21]

Thermoelectric performance was studied under four different types of cooling methods with temperature gradient modeling. The results emphasis that it is important in TEG system design to choose an optimal area that is appropriate to the mass flow rate of the fluids, but this is not affected by the intake temperature of fluids. With the water cooling method, the co flow and counter flow methods did not need to be distinguished because of their small difference, but they should be distinguished for the air cooling method. The counter flow arrangement generally produced a small higher maximum power output, but needed a much larger module area compared to the co flow method. [22]

The present work stimulates optimum design of thermoelectric device in conjunction with heat sinks. The present optimum design includes the power output (or cooling power) and the efficiency (or COP) simultaneously with respect to the external load resistance (or electrical current) and the geometry of thermo elements. [23]

The design performances of different heat

exchangers were thoroughly assessed on their corresponding optimized subsystem designs. Electrical connection of different styles for thermo-electric generator (TEG) modules as an subsystem and their influences was studied. The subsystem configuration is optimized further and thus a better subsystem output power is attained. Balance between the subsystem performance and complexity, a 3-branch scenario was chosen. This increased the subsystem power output by 12.9%. The current TEG modules of the subsystem only have a ZT ¼

Under this condition, the subsystem can boost the fuel cell system power output by around 3.5%. With achievements in material science, this number can be expected up to 10% in the near future. [24]

The present study presents an innovative approach on power generation from waste of IC engine based on coolant and exhaust. The waste energy harvesting system of coolant (weHSc) is used to supply hot air at temperatures in the range of 60–70^0C directly into the engine cylinder, which would be useful to vaporize the fuel into the cylinder. The waste energy harvesting system of exhaust system (weHSex) has been developed within teg rating fuzzy intelligent controlled Micro- Faucet emission gas recirculation (MiF-EGR) and thermo electric generator (TEG).

In this study the MiF-EGR (micro-facet exhaust gas recirculation) will be used to maintain the intake temperature70^0C by keeping flow of the exhaust to the engine cylinder chamber and to increase the engine volumetric efficiency. The TEG produces electrical power from heat flow across a temperature gradient of exhaust and delivers DC electrical power to the vehicle electrical system which could reduce the load of the alternator by as much as 10%. The performance of we HS equipped engine has been investigated by using GT suite software for optimum engine speed of 4000rpm.The result indicate that specific fuel consumption of engine has improved by 3%. While, the brake power has been increased by 7% due to the fuel atomization and vaporization at engine intake temperature at 70^0C. [25]

A mathematical model for the theoretical limit of power generation that provides better electrical loading conditions at a given exhaust gas heat was developed. This analysis emphasizes that there would be an optimum number of thermoelectric leg pairs that maximize the power extracted for any system, and adding more leg pairs beyond this optimum can degrade system performance drastically. [26]

III. *CONCLUSIONS*

From the present review following conclusions can be derived,
1. Thermo electric power generation technology can be applied to automobiles effecttive ly.
2. The power that is generated from thermo electric generator can be utilized as a power source to different sub systems of the automobile.

3. Power that can be generated using thermo electric generator would range between 18 w – 90 w under different conditions.
4. The power that is generator depends upon different factors such as exhaust gas temperature, thermal insulation, material used, vehicle driving conditions, design of the thermo electric generator.
5. Thermo electric generator can also operated from the heat that is recovered from the combustion chamber.
6. There are certain limits of thermo electric power generation such as very high temperatures, electric loading, thermo electric leg pairs, and material availability.

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