Utilization of Waste Heat From Thermo-Electric Generators

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Abstract

A Thermo-electric generator is a solid state device that converts heat flux into electrical energy by using the principle of Seebeck effect. This device is also known as Seebeck generator, they act likes heat engines with no moving mechanism and compact. TEGs is used to recover exhaust waste in IC engines. The edition of this device to the engine exhaust system leads to lowers the back pressure of the engine and increase the overall efficiency of the engine.

The integration of TEGs are coupled with the muffler of the engine without altering the functionality of the muffler to recover the waste heat of the engine exhaust system. The addition of thermos-electric modules (TEMs) to the muffler to generate electricity using the exhaust energy available in the hot exhaust gas.

Pharseology

T = Temperature

α = Seebeck coefficient

V = Voltage

ρ = Resistivity of the thermoelectric material

K = thermal conductivity of the thermo-electric material

$\ddot{\Upsilon}$ = Thermoelectric figure of merit

η = Conversion efficiency

P_{max} = Maximum power of TEG

OCV = Open circuit voltage

R_{int} = Internal resistance of TEM

Introduction

By 2050, the world energy consumption is expected to increase by 45%. Approx. 33.3% of the world energy consumption belongs to transportation sector, in which 75% energy is consumed by the road transportation sector, according to the international energy magazine. Since there is extreme research is going om towards renewable energy resources but the petroleum-based energy sources are dominating in road transportation sector because these energy resources are not reliable, efficient and cost effective. In IC engine nearly 65% of the total energy is wasted as a heat exhaust. Some improvements are held to improve their energy efficiency by in-cylinder techniques but engines have become to its saturation level. So, Bringing a waste heat recovery system. Thermo - electric generators (TEGs), Thermo-acoustic generators (TAGs) are promising to improve the efficiency of the IC engines which will also results in lowering the fuel consumption and greenhouse gas emission.

Thermo-electric generators (TEGs) have been focused as a solid-state technology in which the directly conversion of low-grade energy (Thermal energy) into high grade energy (electrical energy). In context TEGs have been many advantages in the to other energy recovery methods because it has no moving parts, cancellation of noise and vibrations, low maintenance and eco-friendly. *(1,12)*

The electricity produced by the TEG can be directly used to assist the electrical system of the vehicle and hence the size of the alternator of the vehicle can be easily reduced.

Thermo-Electric Principle

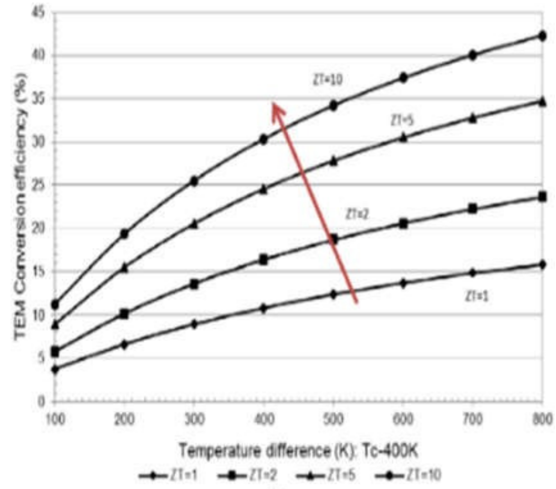
The thermos-electric principle is a way to convert heat energy into electical energy or the reverse of this. The term is generally constrained to the irreversible conversion of electricity into heat. A thermo- electric generator (TEG) consists of several number of thermos-electric modules (TEMs). A TEM consists of several number of serially connected thermos-electric elements and this elements are made of p and n semiconductor materials. The thermos-electric effect is observed in a circuit of two dissimilar conductors. Increasing the number of thermo-electric elements in TEM results into the increment of power generation by a TEM. According to joules law, “It says that a current carrying conductor produces heat is directly proportional to the product of the resistance of the conductor and the square of the current passing through it”.

Around 1800s, Seebeck brought to

dissimilar metals where the junction at which the metals touch are at different temperatures. *(2)*
He observed that a voltage developed between the junctions are proportion to the difference in heat. The current developed is due the difference in temperature at the junction is known as seebeck effect. The current density (J) generated by a TEG can be calculated by the following relation –

$$\mathbf{J = \alpha\ (-\Delta V + Eemf\ )}$$

Since seebeck effect alone is not sufficient to describe the thermo-electric principle, the peltier effect comes into the boundary of consideration. The peltier effect helps in describing the heat loss or absorption or dissipation at the connection of conducting materials. According to the direction of flow current, heat is either dissipated or absorbed by the material at junction. The conversion Efficiency of TE module from heat to electricity is a function of temperature difference across the hot and cold side & the properties of thermos-electric material (like thermal conductivity, electrical resistivity, seebeck coefficient etc.). *(3)*



Materials of TEM –

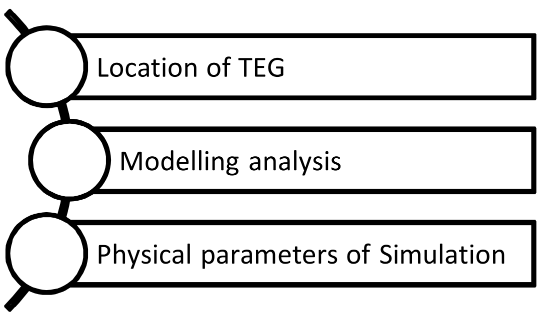
Since thermos- electric generators are not yet popular due its low conversion efficiency. In this modern generation, commercially available TEMs are made of <u>Bismuth Telluride</u> (Bi_2Te_3) material, whose conversion efficiency is less than 10% with a thermos-electric figure of merit (ZT) less than 0.5 which implies that the overall conversion efficiency of TEG is constrained due to its performance boundary from the availability of materials. The thermo-electric figure of merit is a function of temperature and some materialistic property.

$$\mathbf{ZT} = \frac{\alpha^2}{\rho K}\mathbf{T}$$

Since conversion efficiency of thermos-electric material is a function of ZT. Therefore to improve the ZT of TE materials scientist and engineers are making lot of efforts. The conversion efficiency is given as *(4,13)*

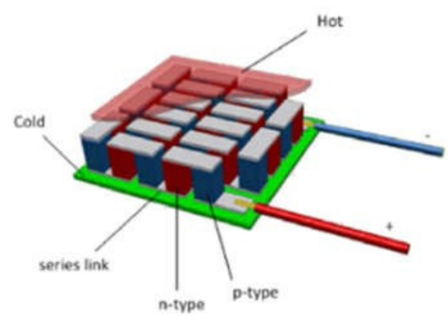
$$\eta = \left(\frac{\sqrt{1+ZTavg}\ \ -1}{\sqrt{1+ZTavg}\ +(\frac{Tc}{Th})}\right)\frac{(Th-Tc)}{Th}$$

Modelling of a Thermo-electric generator



1) Location of TEG :-

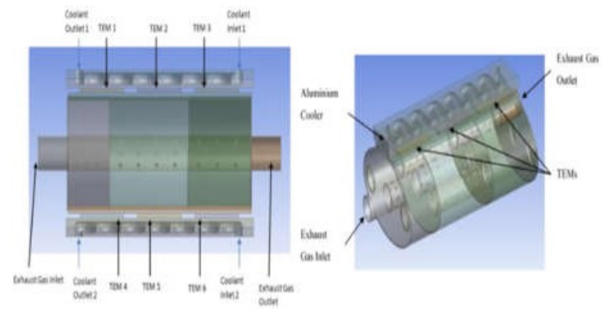
TEGs are functionally designed to retrieve the waste heat from the exhaust gas of the IC Engines (mainly our focus is bounded to the IC engines). In an IC engine there are several component are embedded to form exhaust system like, CAT (catalytic converter), DPF (diesel particulate filter), EGR (exhaust gas recirculation) system, SCR (selective catalytic reduction) system, and resonator to manage the tail pipe emission and the noise as well as adverse vibration. Since exhaust gas that are produced by the IC engine needs to be cleaned during the exhaust stroke through the exhaust system, and to complete this stroke the engine needs to utilise the energy of the burnt gas in the cylinder. *(5,6,7)* As the exhaust gas comes through the above procedure after treatment devices and noise attenuator, a back pressure drops increases with the speed and the load of the IC engine which leads to increase the exhaust gas pumping power and reduces performance o\f the engine drastically.



2) Modelling Analysis :-

An engine dynamometer test is carried out on a modify four stroke V6 engine and to investigate the impact of back [pressure development it is showing that the 11.3 kPa back pressure increment results in

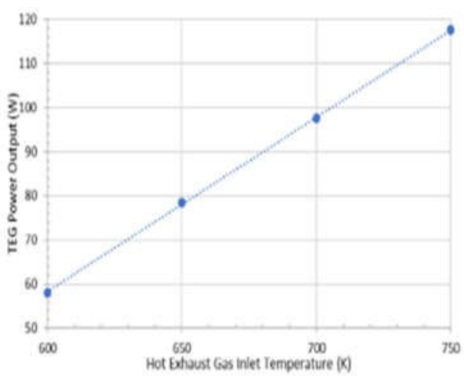
the results of peak torque by 4.9 % and the peak power by 6%while a 16 kPa back pressure increment results a decrement of peak power and peak torque by 8.3 % approximately. The major fraction of overall pressure drop are due to muffler and resonator (55% - 65%).*(6,8,9)*
According to above data it is highlighted that addition of any other heat exchanger device (or waste heat recovery device) to the exhaust system with further lowers the engine performance due to increment in the engine back pressure. The temperature of the exhaust gas at the secondary muffler of a SI engine around 573K whereas the exhaust gas of a CI engine is around 423K . therefore the addition of TEMs to the muffler and develop the muffler as a thermos-electric generation will avoid the additional back pressure increment and will give surety that the summation of TEG – muffler waste heat recovery device to the exhaust system will not deteriorate the performance of the engine and leads to have high possibility to recover the heat from the hot exhaust gas. *(10,11)*
Therefore this analysis results to embedded the TEMs to rear muffler and make the rear muffler as TEG.



3) Physical Parameters of Simulation :-

Para me- ter	$T_{ex.gas}$ (K)	$m_{ex. gas}$ (kg/s)	$m_{coolant}$ (kg/s)	$T_{coolant}$ (K)
Base Case	800	0.2	0.22	355

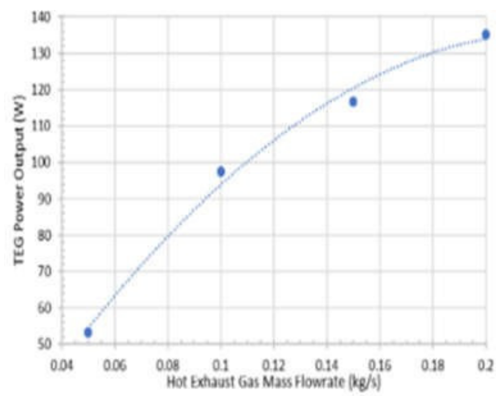
As shown in the above figure, an standard passenger call muffler made of steel or steel alloy was used to mount the TEMs to modify the muffler as the TEG. ANSYS Fluent software is used for modelling and simulation purpose. in the case study, 8 thermo-electric modules (10cm x 10cm x 5mm) are mounted on the body of the muffler. Out of 8 TEMs, half of the total are mounted on either side. Hot exhaust gas is passing through the muffler and raise the temperature of the muffler body. An aluminium (al) allow based plate is fixed to the half muffler body and then TEMs are embedded on the aluminium alloy based. An heat sink setup is provided on the other side of the TEMs to lower the temperature and this is the when a coolant fluid body is mounted on the other side of the TEMs.



Maximum power generated by a TEM can be calculated as the ratio of OCB to the 4 times of the internal resistance and it was defined as an UDF (user defined function, which was developed and defined in the ANSYS fluent program to predict the electrical power output) during the simulation.

$$P_{max}= \frac{OCV}{4Rint}$$

Since simulation where perform reference to the above parameter and thereafter, exhaust gas inlet temperature was varied from 700K – 850K exhaust gas inlet mass flow rate was varied from 0.1kg/sec- 0.25kg/sec, coolant inlet mass flow rate was varied from 0.1kg/sec- 0.25kg/sec and finally coolant inlet temperature was varied from 340 K- 365K.

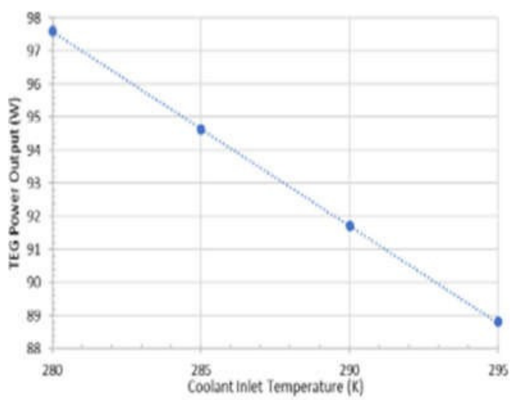


These TEMs are designed to generate 22 watt maximum, when the hot and cold side temperature is maintained at 280K.

So, expecting the maximum power of TEG would be around 200 Watt (approx.). Considering the discontinuous total power generation.

Results and Analysis

The availability of the exhaust gas ranging from 35kW -55kW as the temperature increases from 700K to 850K. the power output is also a function of temperature of exhaust flow which are related as directly proportional.

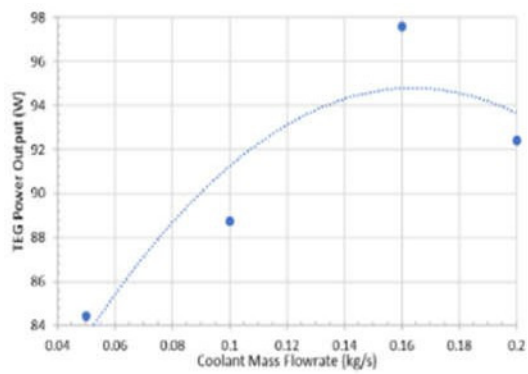


The availability for exhaust gas flow was estimated for various exhaust gas flow rate and found to be ranging between 25kW to 75kW as the exhaust gas mass flow rate ranging from 0.10kg/sec to 0.025kg/sec respectively. Also the power generation by the TEG is directly proportion is the exhaust gas mass flow rate.

The simulation results also focus that the TEG power output is inversely proportion to the coolant temperature, also the TEG power output is not increase as the increasing in the coolant mass flow rate at optimum coolant mass flow rate the TEG power output it maximum but after the optimum the value of mass flow rate.

Conclusion

From the results it is noticed that generation by TEG which is coupled to the exhaust muffler increases when increasing the exhaust gas temperature and the exhaust mass flow rate. TEG power generation is lowers when there is increment in the coolant temperature. The TEG power output can be optimized when selecting the coolant mass flow rate when it is its on optimum level.



When the TEG is attached to the exhaust muffler, waste heat can be recovered without abdicate and additional back pressure in engine exhaust system it is because the pressure drop created in the muffler is directly proportion to the exhaust mass flow rate which will result into the increment of break specific fuel consumption (BSFC) and the overall efficiency of an IC engine can be unaltered . So that exhaust heat recovery can be impressively enhanced by contriving the TEMs from higher figure of merit (ZT) thermos-electric materials.

As a subsequent work, the proposed thermo-electric generator can be integrated with a muffler is expected to embedded and tested to validate the simulation results.

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