# ANALYSIS OF POWER GENERATION FROM THERMO ELECTRIC GENERATOR MODULE BASED ON DIESEL ENGINE COUPLED WITH EXHAUST GAS RECIRCULATION SYSTEM

*Anchal Dewangan[1], Vijay Chaturvidani [2], Abhishek Kumar Jain[3], Vibhor Kulbhaje[4]*

[1]*Assistant Professor, Department of Mechanical Engineering, KITE , Raipur(C.G.)*
[2]*Assistant Professor, Department of Mechanical Engineering, KITE , Raipur(C.G.)*
[3]*Head & Assistant Professor, Department of Mechanical Engineering, KITE , Raipur(C.G.)Assistant Professor,*
[4]*Department of Mechanical Engineering, KITE , Raipur(C.G.).*
*E-mail:,anchal3011@gmail.com, vijay.manit2010@gmail.com, manit.abhi@gmail.com,* vibhor.mech88@gmail.com

## ABSTRACT

***In today's scenario; we have to reduce impact on the atmosphere. Internal combustion engines, being the major power source in the transportation sector as well as in individual transport. While the mobility in the world is growing, it is important to reduce the emissions that result from transportation. Also as it is well known that from our transport vehicles that is from internal combustion engine maximum of amount of exhaust gases exhausted directly to the atmosphere, which contain a lot of harmful gases and also contain lot of heat. Which are believed to be the main cause of global warming. Diesel exhaust contains toxic gases, mainly nitrogen oxides ($NO_x$) and soot particles. These emissions are therefore limited by the authorities in most countries. The only way to utilize this huge amount of heat exhausted from exhaust gases is to adopt a system which will convert heat of exhaust gases into electricity. The name of device is known as TEG (Thermo electric generator) module and the device which tends to reduce the emission of harmful gases is known as EGR (Exhaust gas recirculation) system***

**Keywords:** *Internal Combustion (IC) Engine, Thermo electric generator (TEG), Exhaust gas recirculation (EGR), Exhaust gas,*

## 1. Introduction

### 1.1 Thermoelectric generator and exhaust gas recirculation system

Thermoelectric generator modules are solid device which can convert heat or temperature difference into electrical energy. Thermoelectric elements are made of P type and N type semiconductor. Thermoelectric modules are based on Seebeck effect. When there is a temperature difference between two sides of semiconductor, a voltage is created. Current flows from N type element and passes into P type element. Thermoelectric modules are devices that either convert thermal energy from a temperature gradient into electric energy or vice versa, convert applied electric energy into a temperature gradient. [1]. The Seebeck coefficient (frequently measured in microvolts/K) is defined as the open circuit voltage produced between two points on a conductor when a uniform temperature difference of 1 K is applied between those points.

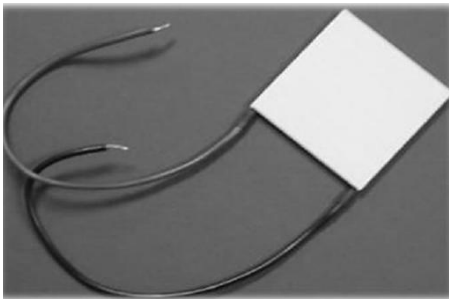

 

**Figure 1.1 TEG module**

In internal combustion engines, *Exhaust Gas Recirculation* (EGR) is a nitrogen oxide ($NO_x$) emissions reduction technique used in petrol/gasoline and diesel engines. EGR works by recalculating a portion of an engine's exhaust gas back to the engine cylinders. This dilutes the $O_2$ in the incoming air stream and provides gases inert to combustion to act as absorbents of combustion heat to reduce peak in-cylinder temperatures. NOx is produced in a narrow band of high cylinder temperatures and pressures. This can be achieved either internally with the proper valve timing, or externally with some kind of piping, Figure 1.2 shows this schematically. The exhaust gas acts as an inert gas in the combustion chamber, it does not participate in the combustion reaction. This leads to a reduction of the combustion temperature by different effects. The fuel molecules need more time to find a oxygen molecule to react with, as there are inert molecules around.

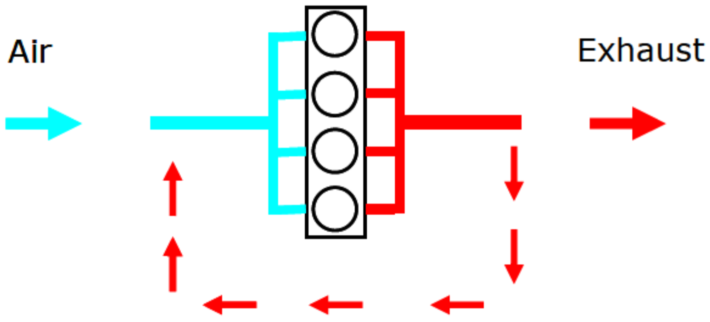


**Figure 1.2 Exhaust gas recirculation system**

### 1.2 Thermoelectric generator material

Among the vast number of materials known to date, only a relatively few are identified as thermoelectric materials. Thermoelectric materials can be categorized into established (conventional) and new (novel) materials. Today's most thermoelectric materials, such as Bismuth Telluride (Bi2Te3)-based alloys and Pb-Te-based alloys, Effective thermoelectric materials should have a low thermal conductivity but a high electrical conductivity. Material with range of temperature for which TEG is made is given in the table below.

**Table: 1.1 Thermoelectric generator material with range of temperature**

| S.no. | TEG Material | Range of temperature |
|---|---|---|
| 1 | Alloys based on Bismuth (Bi) in combinations with Antimony (An), Tellurium (Te) or Selenium (Se) | Low temperature up to around 450K |
| 2 | Materials based on alloys of Lead (Pb) | Intermediate temperature up to around 850K |
| 3 | Material based on Si-Ge alloys | Higher temperature upto1300K |

 

### 1.3 Thermoelectric theory

The thermoelectric power generation is based on the Seebeck effect – If heat is applied to a circuit at the junction of two different conductors, a current will be generated. Thomas Johann Seebeck observed that the magnitude of the voltage generated was proportional to the temperature difference and depended on the type 6 of conducting material, but was unaffected by the temperature distribution along the conductors. Seebeck tested a wide range of materials, including the naturally found semiconductors ZnSb and PbS. [2]

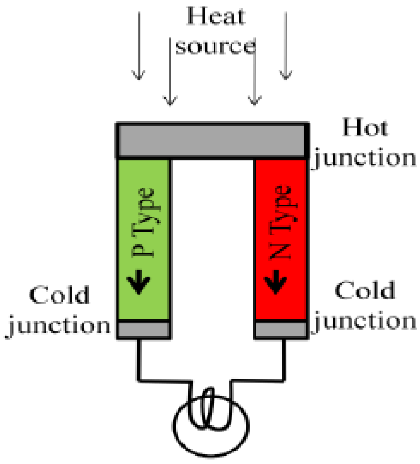


**Figure 1.3 Thermoelectric power generation**

### 1.4 Different EGR-Systems

#### 1.4.1 Short route system (SR)

In the short-route (SR) system, a pipe leads some of the exhaust gases from the exhaust manifold into the intake manifold where it is mixed with the fresh air. The pipe usually contains one or more coolers for the EGR and a valve to regulate the amount of EGR. The valve can be placed on either the hot or the cold side of the cooler. A placement on the hot side gives advantages in transient response [3], while a placement on the cold side makes the choice of valve easier, as it will be placed in a colder environment.

#### 1.4.2 Long-Route System (LR)

In the long-route system, the EGR is taken out of the exhaust system downstream of the turbocharger and driven into the intake upstream of the compressor,. This leads to a higher power input into the turbocharger, as the whole exhaust stream passes the turbine.

## 2. Related work

### 2.1 Duct Specification

TEG module works between hot junction and cold junction. Rectangular duct shown act as hot junction for TEG module in which hot exhaust gases flows. For cold junction of TEG a similar duct is made in which cold fluid is made to flow. Figure below shows combination of both duct with TEG sandwiched in between.

The specification of duct is given below:

 

Shape of duct: Rectangular

Size of duct: 13 cm× 4 cm× 3 cm

Material of duct: Stainless steel

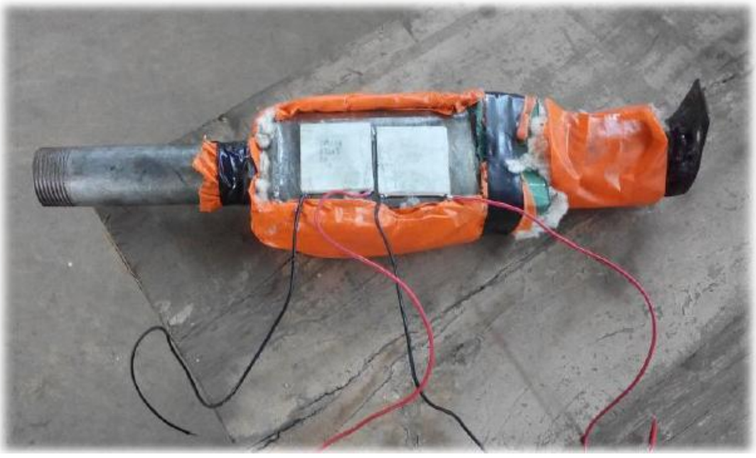

**Figure 1.4 Duct specification with TEG module**

## 2.2 Description of TEG module and EGR system coupled with engine

TEG module coupled with EGR system is shown in figure below. TEG converts heat directly into electricity. Exhaust gas exhausted from the exhaust manifold first passes through the TEG modules which are connected in series and then passes through the different units of EGR system which is shown below. The exhaust gas acts as an inert gas in the combustion chamber, it does not participate in the combustion reaction. This leads to a reduction of the combustion temperature by different effects. The fuel molecules need more time to find oxygen molecule to react with, as there are inert molecules around. This slows down the combustion speed and thus reduces the peak combustion temperature, as the same amount of energy is released over a longer period of time. As the air is diluted with exhaust gas, the mass of a gas portion containing the needed amount of oxygen gets bigger.

The lower combustion temperature directly reduces the $NO_x$ formation, as the $NO_x$ formation rate is highly temperature dependent.

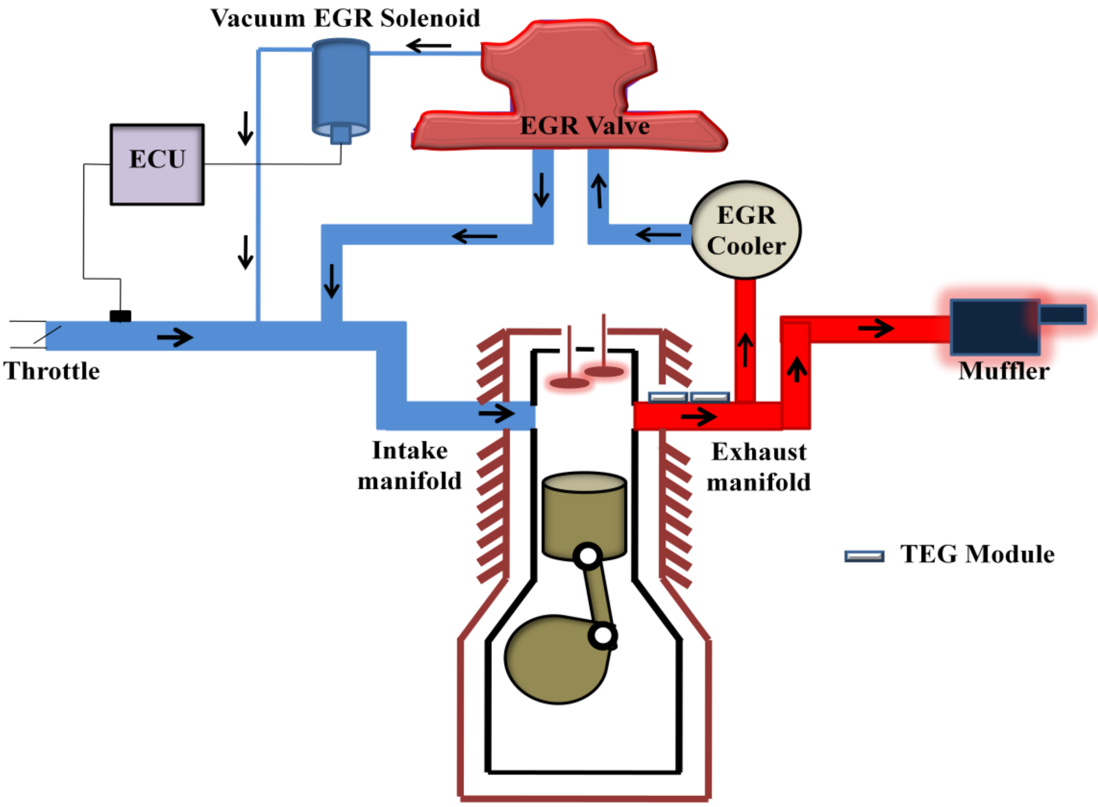


**Figure 1.5 TEG and EGR system coupled with Engine**

### 2.3 Calculation of brake power of engine

Brake power from the diesel engine is calculated by

$BP=T\times\omega$, where

BP is brake power of engine

T Torque generated

$\omega$ is angular velocity (in rad/sec) of engine

### 2.4 Calculation of amount of heat contained in exhaust gases

Amount of heat contained in hot exhaust gases can be calculated by

$$Q_{eg} = m_{eg} \times C_{peg} \times (T_{gi} - T_{go})$$

Where

$m_{eg}$ = Mass flow of exhaust gases (kg/s)

$C_{peg}$ = Specific heat of exhaust gases (kJ/kg K)

$T_{gi}$ = Exhaust gas inlet temperature to calorimeter (in $^{o}$ C)

$T_{go}$ = Exhaust gasoutlet temperature to calorimeter (in $^{o}$ C)

## 2.5 Calculation of electrical Power obtained from TEG

Power obtained from TEG module when connected between the hot source and cold sink is given by

$$W_{TEG} = \frac{V_{TEG}^2}{4r}$$

 

Where,
$W_{TEG}$ is power obtained from TEG
$V_{TEG}$ is voltage generated by TEG teminal, which can be obtained by using voltmeter
r is load resistance of TEG module

## 2.6 Calculation of EGR rate

Another way to express the amount of EGR is the EGR-rate, which is defined as follows

$$EGR\% = \frac{\dot{m}_{exhaust,\text{int}ake}}{\dot{m}_{exhaust,\text{int}ake} + \dot{m}_{air,\text{int}ake}}$$

## 3. Experimental result

Experiment is done for calculation of temperature at cold side of duct, temperature at hot side of the duct, voltage generated, current, internal resistance, heat absorbed by hot side of TEG, Heat received by the cold side of TEG and Power obtained from TEG.
In this calculation load varies from 2 kg to 20 kg, speed of engine is kept constant equals to 1300 RPM

**Table: 1.2 Calculation of different parameters required to calculate power generated from TEG module**

| Sn. | Load (Kg) | Temp. at hot side of duct in degree Celsius | Temp. at cold side of duct in degree Celsius | Voltage generated (V) between terminals in volt | Current (I) in amp | Internal resistance r in ohm | Heat absorbed by the hot side of TEG Qh in Watt | Heat received by the cold side of TEG Qc in Watt | Power obtained from TEG in Watt |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 122 | 16 | 3.5 | 0.519 | 0.2731 | 325.5 | 317.31 | 11.21 |
| 2 | 4 | 126 | 16 | 4.2 | 0.523 | 0.3220 | 343.0 | 332.89 | 13.69 |
| 3 | 6 | 127 | 16 | 4.26 | 0.525 | 0.3245 | 346.5 | 336.09 | 13.98 |
| 4 | 8 | 131 | 16 | 4.32 | 0.529 | 0.3234 | 358.5 | 347.54 | 14.43 |
| 5 | 10 | 137 | 16 | 4.6 | 0.531 | 0.3380 | 377.8 | 365.70 | 15.65 |
| 6 | 12 | 145 | 16 | 5.2 | 0.586 | 0.3396 | 410.3 | 394.49 | 19.90 |
| 7 | 14 | 156 | 16 | 5.75 | 0.596 | 0.3598 | 447.3 | 428.51 | 22.97 |
| 8 | 16 | 165 | 16 | 6.28 | 0.605 | 0.3791 | 478.7 | 456.91 | 26.00 |
| 9 | 18 | 172 | 16 | 6.5 | 0.611 | 0.3825 | 501.1 | 477.60 | 27.61 |
| 10 | 20 | 179 | 16 | 6.86 | 0.618 | 0.3929 | 525.1 | 499.30 | 29.94 |

Figure below shows graphical representations of variation of heat absorbed by hot side of TEG and heat received by cold side of TEG with load variation of 2 kg to 20 kg at constant speed of 1300 RPM, when cold fluid at 16 degree Celsius is flowing through duct

 

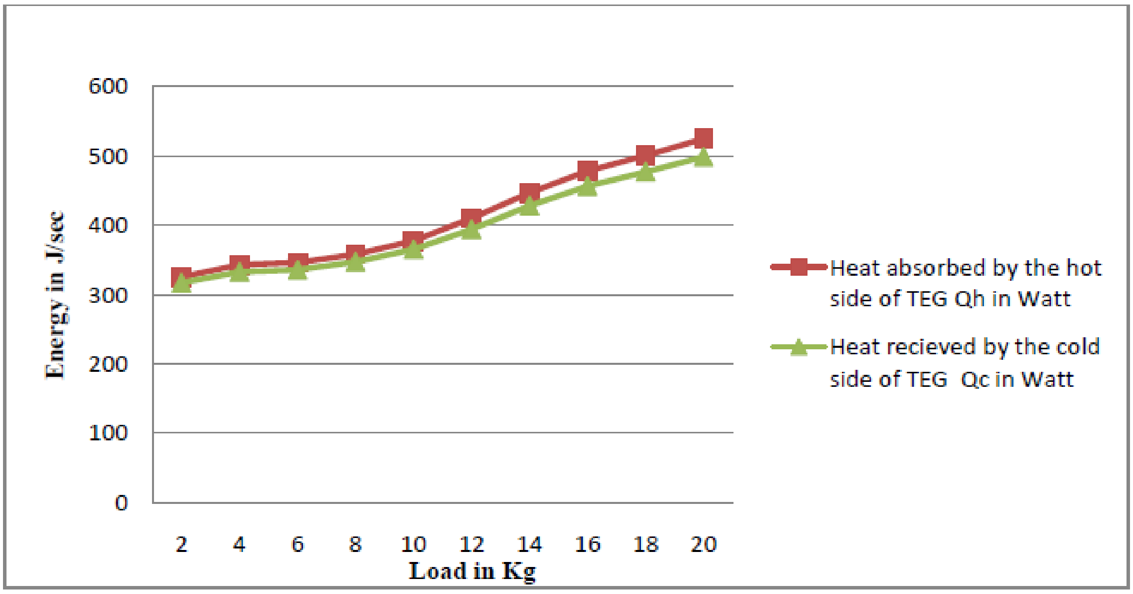


**Figure 1.6** Graphical representations of variation of heat absorbed by hot side of TEG and heat received by cold side of TEG with load variation of 2 kg to 20 kg at constant speed of 1300 RPM,

Figure below shows graphical representations variation of power obtained from TEG with load variation of 2 kg to 20 kg at constant speed of 1300 RPM, when cold fluid at 16 degree Celsius is flowing through duct.

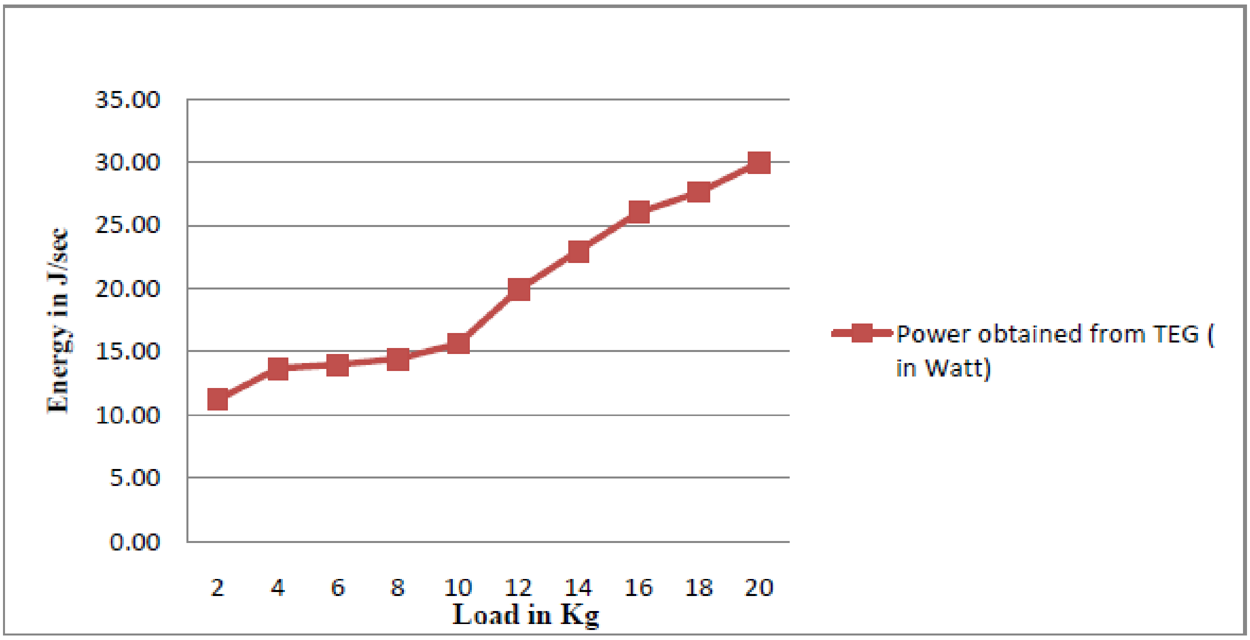


**Figure: 1.7** Graphical representations variation of power obtained from TEG with load variation of 2 kg to 20 kg at constant speed of 1300 RPM

 

## 4. Results and Conclusion

Calculation is made for speed of the engine of 1300 RPM and load variation of 2 kg to 20 kg. At 1300 RPM and from 2kg to 20 kg different parameters like heat absorbed by the hot side of TEG in Watt, heat received by the cold side of TEG in Watt and power obtained from TEG in watt. It is observed that maximum power from TEG is obtained when experiment is done for load of 20 kg and speed of 1300 RPM which is 29.94 watt.

By applying EGR system at the exhaust manifold of the engine the concentration of harmful gases like $NO_x$ can be minimize to certain level.

Hence by applying TEG module and EGR system on engine exhaust, performance of the engine can be increased by utilizing heat of exhaust gases and by reducing the concentration of the harmful gases by coupling EGR with engine exhaust manifold.

## 5. References

[1]. Gequn Shu, Jian Zhao, Hua Tian, Xingyu Liang, Haiqiao Wei. Parametric and exergetic analysis of waste heat recovery system based on thermoelectric generator and organic rankine cycle utilizing R123, 28 July 2012.

[2]. Basel I. Ismail, Wael H. Ahmed, 2009. Thermoelectric Power Generation Using Waste-Heat Energy as an Alternative Green Technology. Recent Patents on Electrical Engineering Vol.2, 27-39

[3]. Mohd Izam Abd Jalil and Jahariah Sampe. Experimental investigation of thermoelectric generator modules with different technique of cooling, 2013. American Journal of Engineering and Applied Sciences,Vol.6: 1-7

[4]. Yuchao Wanga,b, Chuanshan Dai, Shixue Wang, 2013.Theoretical analysis of a thermoelectric generator using exhaust gas of vehicles as heat source. Applied Energy, 1-10

[5]. Maogang He, Xinxin Zhang , Ke Zeng , Ke Gao, 2011. A combined thermodynamic cycle used for waste heat recovery of internal combustion engine; Energy Vol. 36, 6821-6829

[6]. Xin Gao, Søren Juhl Andreasen, Min Chen, Søren Knudsen Kæ, 2012. Numerical model of a thermoelectric generator with compact plate-fin heat exchanger for high temperature PEM fuel cell exhaust heat recovery; Internal National Journal of Hydrogen Energy, Vol.37: 8490-8498

[7]. R. Saidur, M.Rezaei, W.K.Muzammil, M.H.Hassan, S.Paria, M.Hasanuzzaman, 2012. Technologies to recover exhaust heat from internal combustion engine. Renewable and Sustainable Energy Reviews, Vol. 16:5649–5659

[8]. Reifarth, S., Ångström, H.-E., Transient EGR in a longroute and short-route EGR-system, ASME ICES2009-76107

[9]. Charlton,S., Heavy duty diesel emission control symposium, presentation,2007

 