Thermoelectric Exhaust Energy Recovery for I.C. Engine: A Review

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Abstract— **Fuel Economy and environment pollution of I.C. engine is severe problem worldwide, as fuel prices touching high value, increasing in number of vehicle. Use to make more pollution so to vanish this effect and to have economical engine in terms of fuel saving management. From 100% of Heat supplied to fuel only 40-45% of Heat is converted into mechanical work and other is frictional power so to use exhaust gases as a source of heat supplied again to engine can reduces pollution the desired system known as Exhaust Gas Recirculation System and other way to incorporate power from exhaust gas is thermo electric generation as exhaust gas of I.C. engine have ample amount of energy so to utilise it system is necessary called as thermo electric generator so as to impart stream of exhaust gas on surface of it and to generate small electric D.C .type of current depending upon temperature difference across intercooler or heat exchanger is installed in path of Exhaust Gas Recirculation running on Seebeck effect. So this is nothing but duel effect of waste heat can be used to reduce pollution as well can be able to generate small electric current D.C. type so can be able to charge battery ,tail lamp, head lamp. Parking light, door light, Indicator Lamp, G.P.S. system, Night Vision Camera etc.so as to reduce Frictional Power against alternator can save fuel.**

Index Terms—**EGR, I.C. engine, Intercooler, Thermo electric generator**

I. INTRODUCTION

In recent years the scientific and public awareness about increasing prices of fuel and pollution issues has bought in major interest to the research and technology field especially highly efficient internal combustion.

In cylinder no. of cycles i.e. irreversibility's cycles playing its important role of caring work output by engine by heat supplied. All those processes carried out in cylinder and due to these transfer from the fluid to the cylinder wall and piston assembly and to the piston crown. According to four stroke cycle exhaust stroke contain the un burnt particles, exhaust gas after completion of power stroke except from exhaust manifold and exhaust valve & last to the exhaust pipe in these waste heat large amount of energy bounded with exhaust stream so can be used to generate electricity

In these particular study engine used for research work is single cylinder four stroke water cooled C.I. Engine under which current study shows the overall use of waste exhaust gas in to usable form i.e.

1] Used to reduce pollution mainly NO by EGR system
2] Thermo electric generation.

So, significantly due to higher efficiency and lower fuel consumption by improving fuel economy indirectly and also reduce harmful gases such as oxides of nitrogen NO.

Zhang X,Chau,KT states that the waste heat generated from petrol engine is as high as 30-35% also from 100%,25% of heat is utilized to produced the vehicle and technical description is well discussed in paper[15].Author Miller EW [9] investigated the percentages of fuel energy that would be converted into useful work i.e. 11% and also found the heat energy containing exhaust stream is of 27% is of no use. The second law i.e. exergy about fuel analysis shows the fuel energy is converted in to brake power and got a value by experimentation as 9.7% and exhaust about 8.4% respectively.

The value of exhaust gas mentioned as a 18.7%of total fuel consumption and can be saved up to 33.9% by installing intercooler or heat Exchanger.[2,3].
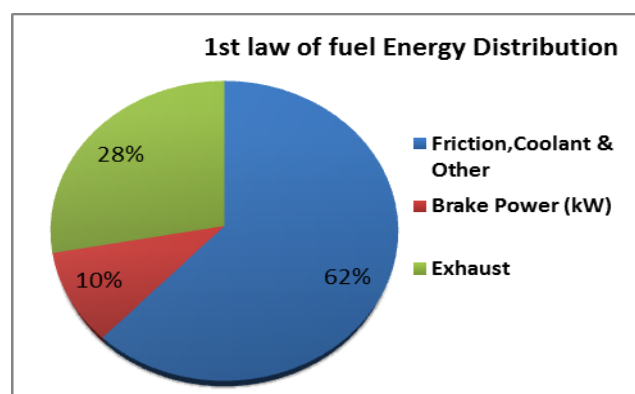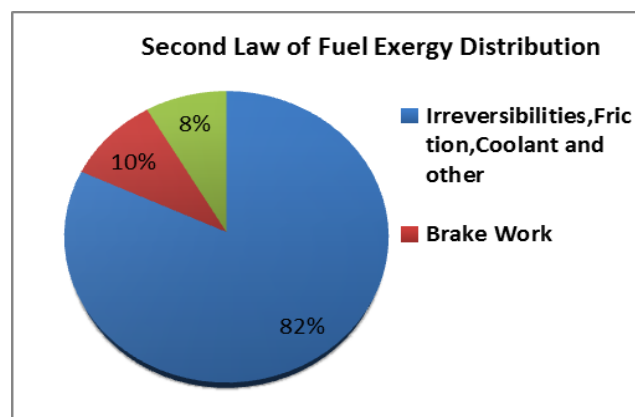

Fig 1 1st law of fuel Energy Distribution

Fig 2 Second law of Fuel exergy Distribution

II. DEVELOPMENT OF THERMO ELECTRIC ENERGY CONVERSION SYSTEM

Basics of thermo electric generator

Thermo-electric module is new technology being used in automotive sector from 2006 onwards worked on the

principle of see beck effect Thermo Electric Generation become promising to the new technology that any other because everyone knows day by day there is increment in fuel prices and pollution so; these comes practically into pictures. R Saidur et al[3]studied effect of thermo electric waste heat recovery for hybrid vehicle.R saidur[3]shows the energy developed by TEG device is near about 1-3kW from exhaust of I.C. Engine by doing study on it he found that 1-3kW of electrical load get reduced from alternator so as to increase B.P.in same quantity of fuel so there is reduction in fuel consumption.

In this paper Pratik G.Sapre achieve same technique to generate electrical power from Thermo Electric Device and to extract more energy from exhaust and with the help of modern intercooler can increases the temperature difference cause to have efficient electricity production. so to incorporate the use of TEG module will increase overall performance of Engine. The Thermo Electric Generator worked on principle of see beck effect. Scientist Thomson Johann Seebeck states the temperature Gradient present between cold and hot junction cause to generate voltage across it. These is simple in structure light weight no moving mechanical parts and easy to use or installation in I.C. Engine exhaust.

The main reason behind improving fuel economy is to lower down the torque on alternator drive. Alternator is power developed and creating device installed on assembly by use of pulley belt arrangement. If TEG module generate electricity indirectly reduces load on alternator drive so we can say it can reduces the torque developed by electronic appliances so that Brake Power increases and F.P. reduces so that fuel consumption reduces.

Figure 3 shows schematic arrangements of heat source and heat sink couple view containing P-N junction module. This module is enclosed in two plate one is having surface area exposed to heat sours as a exhaust stream and other is having stream of cold exhaust gas. The CAD model of intercooler arrangement is developed to generate electricity

heat sink and this temperature drop could be possible by intercooler or hear exchanger arrangement as shown in CAD geometry.
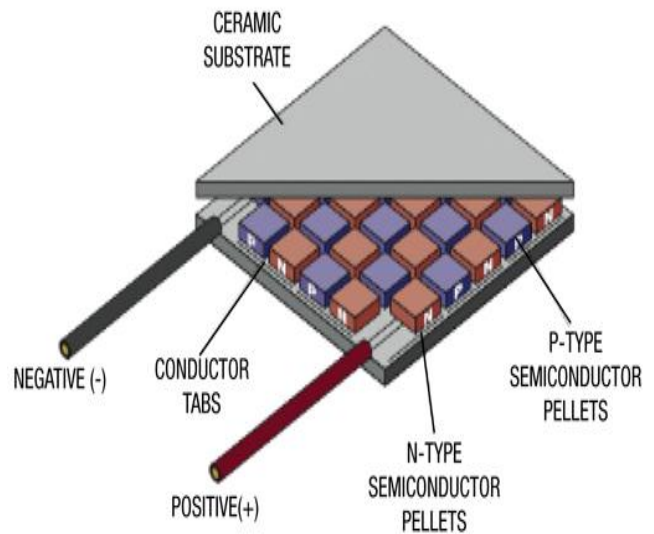

Fig 3 Schematic of a typical thermoelectric module assembly

Above figure included pellets of P & N type semiconductor arranged in parallel shape, assembled in plate type substrate which is made up of ceramic material. The performance of a thermo electric material can be expressed as $ZT=S^2T/kp$, where S is thermo power, T the absolute temperature, k the total thermal conductivity, and p the electrical resistance. The performance & efficiency of voltage generation is depend upon material selection i.e. thermo electric figure of merit Z. The terminal output having electric charge to drive electrical appliances of vehicle. So ultimately reduced torque on alternator.
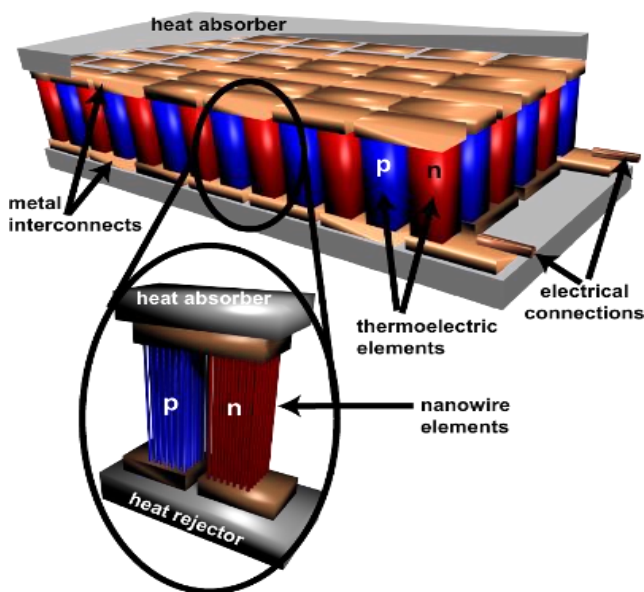

Fig 3 Schematic of a typical thermoelectric device

Typical zoomed view of above mention module consisting of packets of p-N junction diode having attachment of two surfaces known as heat source and heat sink. Heat source is having high temperature i.e.150-250°C and other known as
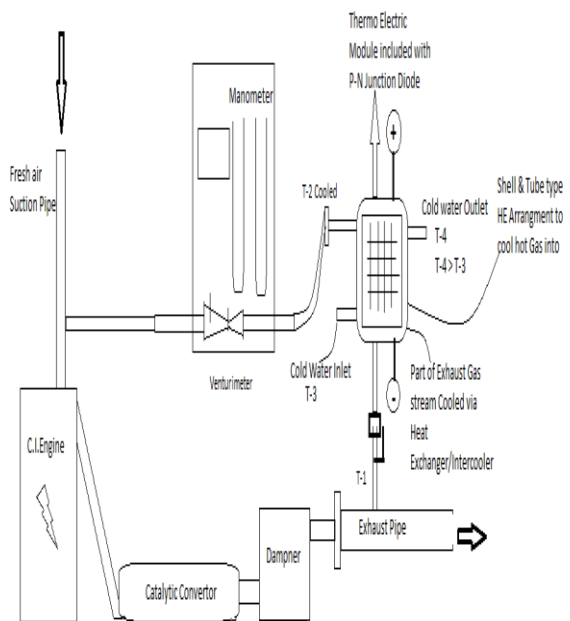

Fig 4 Experimental layout of single cylinder 4 stroke C.I. engine equipped with Intercooler/Heat exchanger installed with Thermo Couple Generator Module.

Fig 5 Internal Arrangement of Heat Exchanger to cool Hot exhaust gas into lower temperature T-1=190°C>T-2=75°C

As shown in figure 4 i.e. experimental layout heat exchanger arranged in path of Exhaust Gas Recirculation system to cool the hot exhaust gas into cold one so to achieve cooling effect counter flow heat exchanger is design to have maximum heat transfer to the cooling fluid which is circulated around the aluminum tube. Material used of aluminum having maximum heat transfer rate so to achieve maximum temperature across heat exchanger so that seebeck principle play working role and to have voltage output as a main parameter ti generate electric D.C. Current by TEG module.TEG module arrange peripheral side of heat exchanger so that from hot side it acts as a heat source and cold side acts as heat sink so to have maximum ΔT
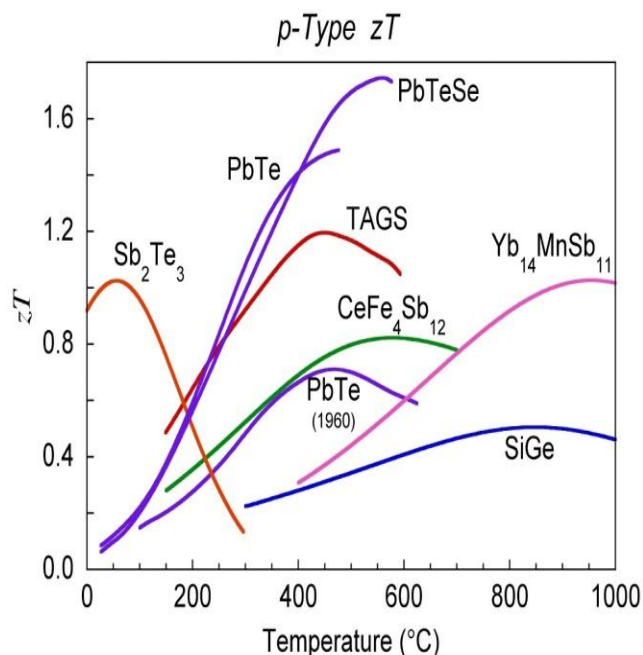

Fig 6 Variation of figure of merit w.r.t Temperature °C

As shown in figure zT is material figure of merit which varies as per temperature of working media changed. So depending upon the working temperature of media in which it gives appropriate thermal efficiency as well output voltage. So substrate used in particular study is ceramic material having working range 200-500°C.So under varying temperature range it gives continuous value of voltage under varying stream flow of exhaust.
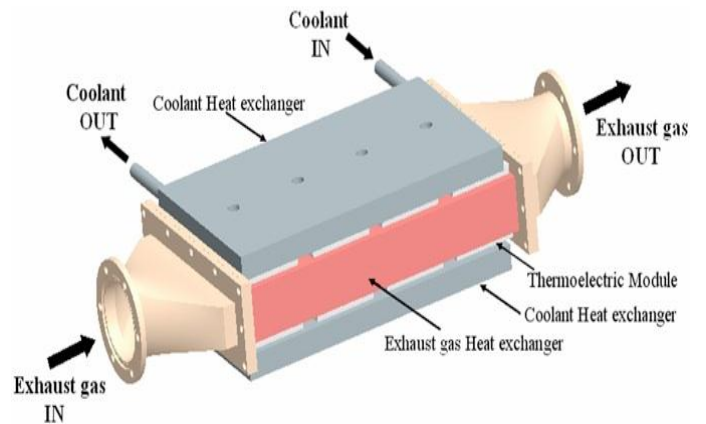

Fig 7 CAD Model of Heat Exchanger equipped with TEG module

As shown in fig 4 heat exchanger is installed with TEG module so to have simulation of working model and find out performance of heat exchanger CAD model is design. We will discuss performance of heat exchanger equipped with TEG module in further study.

Now waste heat recovery and thermo electric generation is combined effect from which we can generate electricity as well to reduced pollution Exhaust Gas Recovery is important

Waste heat recovery has two benefits one is direct and other is indirect benefits as in direct benefits it have stringent positive effect on combustion process efficiency & other is to reduce pollution containing harmful gases such as oxides of nitrogen NOx,CO,HC etc.so this can be reduced by doing arrangement as shown fig 4.So as to called as Exhaust Gas Recirculation Technique in which exhaust gas is cooled with the help of heat exchanger and passed to the inlet head so to increase the specific heat of g as mixture under cylinder which maintained peak pressure under cylinder. Due to this reason emission reduced up to 65% found by Pratik G.Sapre[7].

A. Potential to develop waste heat from I.C. engine

Today's life mostly depends upon automobile vehicle i.e. internal combustion engine. From heat power engine, C.I. engine is mostly used for private and government sector.

Sr no	Engine Type	Power output(kW)
1	Agriculture tractor & Small Crane	35
2	Small Air cooled diesel engine	150
3	Water cooled engine	34-140
4	Earth movers engine	520-720
5	Marine Applications	152-223
6	Heavy Trucks & road engine	220

Table 1 Different field application Engines and there Outputs

B. Potential of waste heat expelled from engine Exhaust Pipe.

The quantity of exhaust gas expelled from exhaust is both combination of exhaust gas mass flow rate as well temperature can be given as

$$Q = m \times C_p \times \Delta T$$

Where Q is heat loss in kJ/min
M is exhaust mass flow rate in kg/min
Cp is specific heat of exhaust Gas in kJ/kg°k
ΔT is temperature gradient in°K

So this much amount of waste heat energy is impinges on per unit surface area of thermo electric module so as to have proper output can be developed. The source temperature must be high than sink temperature and this can be possible by installing heat exchanger in rout system as shown in fig 4.

C. Temperature Range for Diesel engine

Sr no	Engine	Temperature In °C
1	***Single cylinder four stroke diesel Engine kirloskar***	350
2	Four Cylinder four stroke Diesel Engine(Ford Figo)	452
3	Six Cylinder Four stroke Diesel Engine(Mahindra sarpanch 575 DI)	305
4	Genset(Kirloskar) @ power 198 hp	398

Table 2 Temperature Range for Diesel Engine

In above table enlisted power developing unit of engine from different application area from that single cylinder four stroke C.I. water cooled engine made by kirloskar is under investigation.

D. Heat loss via the exhaust line in internal combustion engine

"Current study of establishment and installation of thermo electric generator carried with single cylinder four stroke water cooled C.I. engine located in Babasaheb Naik college of Engg., Pusad, 445215, MH, India".

Engine Specification

4 Stroke single Cylinder air cooled self start CI engine.	Make:-Kirloskar
Rated Power:-7.5kW (10 HP)	Bore Dia.:-80mm
Stoke Length:-110mm	Connecting Rod Length:-234mm
Swept Volume:-562cc	Compression Ratio:-17.5:1
Rated Speed:-rpm	Rated Torque:-4.6kg-m
Arm Length:-150mm	

Table 3 Engine Specification

Exhaust Heat Lost from engine exhaust

Compression ratio(Vr)

$$= \frac{Vc+Vs}{Vc}$$

$$17.5Vc = Vc+Vs$$

$$17.5Vs=Vs+5.62\times10^{-4}$$

$$Vc=3.40\times10^{-5}m^3$$

Total Volume(Vt) = Vc+Vs
$$= 3.40\times10^{-5}+5.62\times10^{-4}$$
$$\mathbf{= 5.96\times10^{-4}m^3}$$

Mass flow rate of fuel can basis of specific fuel consumption,

$$\bullet m_{f=?}$$

So further, Specific Fuel Consumption S.F.C.is given as;

$$= \frac{mf}{power}$$

$$m_f = S.F.C.\times Power$$
$$=547\times7.5kW$$
$$\mathbf{=1.139ms/sec}$$

Volume Rate = Swept Volume× Speed
$$\bullet V = Vs\times\frac{1530}{2}$$
$$= 0.42\times\frac{1530}{2}$$
$$\mathbf{\bullet V= 7.16\times10^{-3} \ m^3 /sec}$$

$\dot{\eta}_v$ =Volumetric efficiency

$$= \frac{Volume \ of \ air}{swept \ volume}$$

$$\dot{\eta}_{v =} \frac{\bullet ma}{pa\times n\times Vs}$$

$$\bullet m_a = n_v \times pa\times n\times Vs$$
$$= 0.9\times1.16\times\frac{1530}{2} \times5.62\times10^{-4}$$
$$= 0.448g/min$$
$$\mathbf{= 7.464\times10^{-3} \ gm/sec}$$

"On free run we have to calculate specific consumption without torque."

$$Brake \ Power.= \frac{2\pi NT}{60}$$

$$= \frac{2\times3.14\times1530\times0.001}{60}$$

Consider Brake Power as a 1watt or near about 1watt; this is due to rotation of Connecting rod, Crank rotation, alternator and flywheel.
S.F.C. is taken as a 547gm/kW-hr

Mass flow rate of exhaust
$$=\bullet m_f +\bullet m_a$$
$$=1.13+7.46$$
$$\mathbf{=8.59\times10^{-3}gm/sec}$$
Now exhaust heat lost from exhaust gas
$$Q_E=m.cp.\Delta T$$
$$Q_E=8.59\times10^{-3}\times1.1\times(430-28)$$
$$\mathbf{Q_E =3.79kJ/sec \ or \ kW}$$

Hence, net amount of heat loss by undertaken research

engine is 49.1%.Hence the loss of heat from exhaust tail pipe of given engine to the environment is found out to be 49.1%.

This amount of energy is utilized for generating electricity we have seen it earlier,

III. DIRECT METHOD

Developing power from waste heat mostly contains waste heat utilized from internal combustion engine to produced mechanical energy to rotate alternator on mechanical power output. But indirectly we can generate electricity directly from heat source such as thermo electric generator and piezoelectric power generation. But considering thermodynamic problem like temperature distribution over surface of TEG module, unequal acceleration of vehicle etc.

Possibilities of generation of electricity from other methods;

A. Piezoelectric Generation

It is used for lower exhaust temperature range 110-160°C.It convert mechanical energy in form of air-gas molecule vibration to electric energy. Arrangement to developed electricity from vibration is from thin film membrane can take advantages of oscillatory gas expansion to create a electric output.

B. Thermoionic Generation

It is type of thermoelectric divide operate on stream flow of exhaust gas thermal energy as a output in which liberation of electron energy is cause to flow in vacuumed so that acceptance ratio of electron can developed small electric current possible at temperature of 1000°C

C. Thermo Photo-Voltaic

It converts radiant heat energy into useful electric power. This is possible by giving thermal energy over emitter emits electromagnetic radiation which is directly proportional to electricity generation. Efficiency of Thermionic Generation is more as compared to other conversion system. This could be possible with low velocity, low grade thermal energy.

IV. CONCLUSION

From investigation and carrying experiments on undertaken engine found that, about **63.25%** harmful emission is get reduced also the fuel consumption is decreased. About **2.5%** of fuel is saved by using thermoelectric generator. From experiment we have got about 20ml of fuel decrement in fuel consumption. Efficiency of intercooler or heat exchanger is increases due to shell and tube type arrangement. So generation of electricity about **250 Watts** in D.C. form is possible. Pollution and performance of engine is stringently improved by waste heat recovery. If this technology applied for all petrol as well as diesel engine (if not installed) then performance as well emission can be improved.

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