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Power Generation from Exhaust Gas of Single Cylinder Four stroke Diesel Engine Using Thermoelectric Generator

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ABSTRACT

A majority of thermal energy in the industry is dissipated as waste heat to the environment. This waste heat can be utilized further for power generation. The related problems of global warming and dwindling fossil fuel supplies has led to improving the efficiency of any industrial process being a priority. One method to improve the efficiency is to develop methods to utilize waste heat that is usually wasted. One of the promising technologies that was found to be useful for this purpose were thermoelectric generators. Therefore, this project involved making a bench type, proof of concept model of power production by thermoelectric modules and heat from the exhaust emissions of engines. The experimental results showed that temperature difference obtained and external loading had an empirical relation with the power generated. An output voltage of 200mV was generated using a single Bi_2Te_3 thermoelectric module for a temperature difference of about 40°C. The proposed system can be used for waste heat recovery from the industry where thermal energy is used in their daily process and also in automotive industry to increase the efficiency of engines.

KEY WORDS: Power Generation, Waste Heat, Thermoelectric, Generator, Exhaust gas.

1. INTRODUCTION

With the ever increasing demand of energy in our day to day life and the fast depleting fossil fuels, there is an urgent need for replenishable, more efficient, and cost effective means or sources of energy production. The utilization of conventional resources can be enhanced by either adopting new technologies for improving conversion rates of fuels or by finding ways to recover energy that is often lost in the form waste.

One of the better suited technologies for recovering waste heat was found to be thermoelectric generators. Thermoelectric generators (TEGs) are solid state device that converts heat directly into electrical energy through the phenomenon of Seebeck effect. Over the last three decades there has been extensive research in the field of thermoelectric power generation. However, many drawbacks were encountered while studying these power generators of which the most common was the low heat-to-electricity conversion efficiency.

Hsiao and Chang (2010), have experimented on TEG and have given mathematical models to show that it performs better on exhaust pipe than on the radiators. Niu (2009), achieved a conversion rate of about 4.44% when 56 BiTe TEG modules were used connected in series for a low temperature heat.

Many suggestions have been made by Gou (2010), for better performance of TEGs such as increasing the temperature of the waste heat and connecting the modules in series, expanding sink surface area of the sink in a feasible range and enhancing the cold side heat transfer capacity. The main objective of this project is to transform the exhaust heat lost to the atmosphere into electricity especially for vehicles and motorcycles. A system thus was designed and fabricated to achieve this objective, as explained in the following sections.

Byung deok In (2015), investigated the effect of fins on the conversion efficiency of the TEG and compared the rectangular, triangular and reverse triangular fins and found that the rectangular fins were the best among the three in increasing the output.

2. EXPERIMENTAL DETAILS

Apparatus used: Four stroke single cylinder diesel engine, Thermoelectric module, Thermal paste at the heat sink, Flexible joint and multimeter, Temperature Gun.

Fig.1. Single cylinder 4-stroke diesel engine under consideration

Four stroke single cylinder diesel engine: Single cylinder four stroke CI engine is used to perform the experiment. The fuel used is HS diesel and the rated power of the engine is 5.2kW at 1500 rpm. The cylinder diameter is 87.5mm and the stroke length is 110mm. The compression ratio is 17.5:1. The diameter of the orifice and the dynamometer arm length is 20mm and 185mm respectively. The engine used has an eddy current dynamometer with mechanical loading. The specific gravity of the fuel used is 0.84 and the calorific value is 42500 KJ/Kg. The coefficient of discharge is 0.6.

The performance of the engine depends on the interrelationship between power developed, speed and specific fuel consumption at each operating condition within the useful range of speed and load.

Thermoelectric module: The material used is Bismuth telluride and the type is thermoelectric generator. Dimension of the module is 40mmx40mmx3.5mm and the recommended operating temperature range is -40^0C to 150^0C. The perimeter is sealed for moisture protection and is filled with six inch Teflon insulated leads. The module comprises of 127 couples and the cable length is approximately 20cm.

Material selection: The thermoelectric generator setup consist of ceramic substrate, electrical insulators, electrical conductors, thermo electric modules and lead wires. The selection of the material for each purpose is based on the cost effectiveness and corresponding thermal conductivities. For high seeback effect the TEM module must have high electrical conductivity and low thermal conductivity, a Bi_2Te_3 module satisfies both the requirement. The base plate must have a decent thermal conductivity not high enough to burn the module such as steel whose thermal conductivity is 50.2 w/mK. For the fin material and fin base plate aluminium is chosen as it is has a thermal conductivity of 206 w/mK and melting temperature of 660^0C. The material that are chosen like aluminium and steel are also cost effective. The temperature has to be monitored continuously using thermocouples or temperature gun because operating the module above the operating temperature might burn it and will render it useless. Thermoelectric module is fixed between the base plates using the screw provided at both the ends and the experiment is performed.

Design of TEG: The Thermoelectric generator along with the fins shown here is designed to achieve the lowest temperature possible on the cold side. The dimension of the setup is 300mmx200mm and the optimum fin spacing is 10mm. The height of the fin is 200mm and the base plates are folded on both the sides using the hydraulic press brakes at 150·and 5mm. The three dimensional design (solid model) that is shown here is prepared in solidworks.

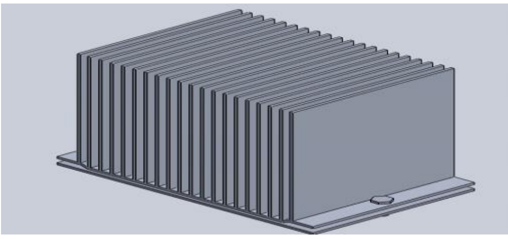

Fig. 2. Thermoelectric generator prototype in solid works

Fabrication process: The entire fabrication process has been done keeping in mind the material melting point and their respective compressive and bending stresses. The fabrication process consisted of material cutting, base plate folding, drilling and brazing operations.

Thermoelectric shield: It is the material which protects the module damage due to high temperature. Mostly ceramic material or steel can also be used depending upon the required temperature gradient. It should be thick.

Thermal fin: It is used to increase the thermal gradient value which in turn increases the seebeck voltage generated by TEG. This fin also transfers the heat from thermoelectric module, it is made up of aluminium metal.

This material cutting process was performed in hydraulic press and the aluminium base plate was cut into 300x200mm and the fins were cut from large plate of size 1220x750 mm into 18 fins of size 250x200mm.

Material folding process is similar to the bending process here the folds are formed due to compression using the hydraulic press brake. Base plate is bended between a gaps of 1cm at an angle of 155 degrees. First the plate to be bended is placed inside the material folding hydraulic press and then the angle and clearance readings were set in the display and machine is switched on. This process is performed several times to gradually reach the final required dimension thereby giving the shape as shown below.

Precaution must be taken while placing the plate in the folding chamber because once the hydraulic button is pressed the ram moves quickly downwards and this can hurt the operator if not performed carefully. This process can also be used as a manufacturing process that can form V-shape, U-shape or channel shape along a straight axis in ductile materials most commonly in sheet metals.

Fig.3. Aluminium base plate folding in hydraulic press

Once the base plate is cut and the aliuminium plate is folded next in line is the drilling process. Two 12mm holes were drilled on both ends of the base plates at the exact centre of the elevated surface for keeping both base plates at a fixed distance using M12 bolt and nut. This op is performed in vertical drilling machine.

After the drilling operation is performed the aluminium fins are attached to the base plate using the brazing operation, the filler metal is drawn through the joint to create this bond by capillary action. In this operation we apply heat broadly to the base metal. The base metal and fins are of aluminium, flux is also aluminium and gases used are oxy acetylene. After the brazing operation is done the entire setup resembles the 3D design drawn in the solidworks.

3. RESULT AND ANALYSIS

Before reaching to any conclusions and carrying out the calculations it is prerequisite to note down the exhaust temperature readings of the engine to be used. This is done using the calorimeter attached to the engine. The exhaust temperature values at various load conditions are shown below:

Table.1. Exhaust Temperature of Ci Engine Used (^{O}c)

Load (Kg)	T1 (cold water)	T2 (hot water)	T3 (before calori.)	T4 (after calori.)	rpm
0	30	32	114	81	1550
3	30	33	115	105	1494
6	30	34	186	127	1478
9	30	34	222	152	1470
12	30	37	262	178	1457

Based upon the above readings the calculations were done and the brake power of the engine was found to be 3.42kW. Volumetric efficiency was found to be 80.35%, brake thermal efficiency and indicated thermal efficiency was 25.96% and 42.29% respectively and mechanical efficiency of 61.4%. The brake mean effective pressure of 413.61 KN/m^2, indicated mean effective pressure of 673.63 KN/m^{2}and specific fuel consumption of 326 Kg/KWhr at the load of 12kg.

The voltage readings have been taken by setting the multimeter to mV scale and then connecting the leads of the multimeter to the terminals of the cable of TEG red to red and black to black, connecting the other way around will only give the reverse polarity. Voltage was found to be around 201mV @temp. Difference of approximately 100^{0}c and current 67.3mA. As the temperature and the load are increased it was found that the current value also increases long with the voltage. The cold side is further cooled by applying cold water to its surfaces and the temperature of the hot side is increased using thermal paste.

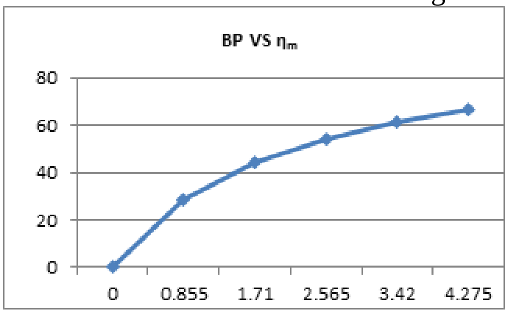

Fig. 4. Brake power (kW x-axis) vs mech. efficiency (% y-axis)

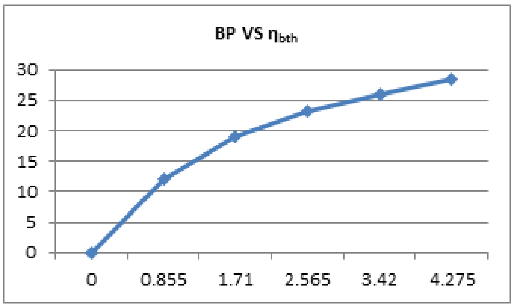

Fig. 5. Brake power (kW x-axis) vs brake thermal efficiency (y-axis)

The voltage and temperature values are recorded by bringing the cables of the thermoelectric module in contact with the leads of the multimeter and the corresponding temperature values are recorded with the help of a temperature gun.

The current I is independent of number of thermocouples and hence the current through one TEG module is given by: $I = \dot{\alpha}(Th-Tc)/R_L+R$

Where RL is the load resistance and R is the internal resistance of the TEG.

The voltage across the module is given by: $Vn= n\dot{\alpha}(Th-Tc)R_L/(R_L+R)$

The maximum conversion efficiency is given by: $\eta_{max}=(1-T_c/T_h)[(\sqrt{1+ZT'}-1)/ (\sqrt{1+ZT'}+(T_c/T_h))]$

$ZT = Z(T_c+T_h)/2$

Table.2. Constant value table taken from manual

Description	Bi2Te3	Bi2Te3	Bi2Te3	Bi2Te3
	Symbol	Hi-Z HZ9 $Tc=50^0C$ $Th=230^0C$	Crystal G-127-10-05 $Tc=50^0C$ $Th=150^0C$	Kryotherm TGM-199-1.4-1.2 Tc=50.C Th=150.C
Total thermocouples	n	98	127	199
Intrinsic material properties	ά(μV/K)	189	-	-
	P(Ώcm)	$1.26x10^{-3}$	-	-
	K(W/cmK)	$1.13x10^{-2}$	-	-
	ZTc	0.811	-	-
Extrinsuc material properties	ά(μV/K)	168.2	225.1	121.3
	ρ(Ώcm)	$1.563x10^{-3}$	$0.677x10^{-3}$	$0.854x10^{-3}$
	K(W/cmK)	$1.18x10^{-2}$	$3.0x10^{-2}$	$1.3x10^{-2}$
	ZTc	0.497	0.806	0.428
Measured geometry of thermoelement	A(mm2)	12	1.0	1.96
	L(mm)	4.62	1.17	1.2
	G=A/L(cm)	0.26	0.085	0.163
Dimensions (WXLXH)	mm^3	62.7x62.7x6.5	30x30x2.8	40x40x3.7

Material Specifications: L= 1.2mm, n=199, A=1.96mm^2, ά=121.3μV/K (seeback coefficient), $\rho=0.854x10^{-3}$Ώcm (eletrical resistivity), $K=1.3x10^{-3}$w/cmK (thermal conductivity), $ά=ά_p-ά_n=242.6x10^{-6}$V/K, $\rho=\rho_p+\rho_n= 1.708x10^{-5}$Ωm, $K=K_p+K_n$= 1.6w/Mk.

Figure of Merit: $Z=ά^2/\rho K = (242.6x10^{-6})^2/(1.708x10^{-5}x1.6) = 1.325x10^{-3}K^{-1}$

Internal Resistance of TEG: $R=\rho L/A =(1.708x10^{-5}x1.2x10^{-3})/1.96mm^2 = 0.0104$Ώ

Voltage across module: $V_n=nά(T_h-T_c)xR_L/(R_L/R+1) = (199x242.6x10^{-6}x100)/2 = 2.413V$.

Current flowing through the circuit: $I=ά(T_h-T_c)/(R_L+R) =(242.6x10^{-6}x100)/(2x0.0104) =1.16A$.

Maximum conversion efficiency: $\eta_{max.}=(1-T_c/T_h)[(\sqrt{1+ZT}-1)/ (\sqrt{1+ZT}+(T_c/T_h))]$, $ZT= Z(T_c+T_h)/2 = 0.494$, η_{max} $=(1.325x10^{-3}x(323+423))/2 = (1-323/423)[(\sqrt{1+0.494}-1)/(\sqrt{1+0.494}+(323/423))] = (1-0.76)(0.222)/(1.922) =0.0264$ = 2.64%.

Table.3. Variation of voltage and current with temperature

Temperature difference	Opencircuitvoltage (V)	Current (A)
20	0.97	0.32
40	1.31	0.41
60	1.73	0.73
80	2.01	0.98
100	2.41	1.16

As load increases temperature increases, so when temperature increases then heat transmission to TEM also increases. So current generation by the TEM will increase, on the other side of the module it should be cooled for better performance and efficiency. The above readings were obtained at a maximum available load of 12 Kg and temperature difference of 100°C.

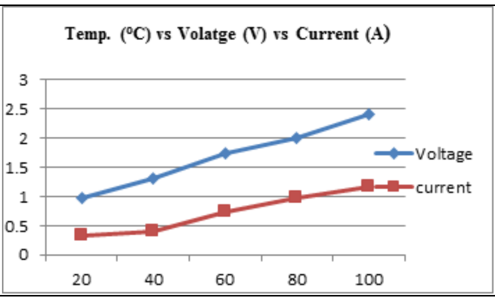

Fig.6. Temperature (Xaxis °C) VS Voltage (V) VS Current (A)

4. CONCLUSION

In this study the performance of a prototype thermoelectric generator was measured under loaded condition of a compression ignition diesel engine. The subjective of this topic makes effort in simulating and testing the performance of Bi_2Te_3 based thermoelectric module. Power outputs with the system are also determined for various temperature differences. The main results of this study are as follows:

a) The performance of the thermoelectric modules increased as the temperature of the hot side was increased, until the durable temperature of thermoelectric module was exceeded, at which point further increases impaired the power generation performance.
b) The experimental results illustrated that the temperature difference between the two ends of the thermoelectric module and the load on the CI engine are key factors in the module's power generation performance.
c) This study presented an empirical correlation for open circuit voltage of thermoelectric generators as a function of outlet temperature of the exhaust gas assuming constant ambient temperature and flow rate.
d) It is determined that having more thermoelectric modules in series connection and higher temperature difference will produce more electric power, rather than having limited number of individual modules for same temperature difference.
e) The thermoelectric generator was fabricated with optimized dimensions and the necessary experiments were performed to calculate total output power generated at specific load condition.

Thermoelectric generators are reliable, feasible, and simple. The high output power and conversion efficiency achieved compensate for the high cost of thermoelectric material. Thermoelectric generators have strong potential to improve thermal efficiency of engines. Future studies focus on optimizing the segments of thermoelectric generators such as enhanced heat transfer and heat exchanger.

Furthermore, it is also important to enhance the thermoelectric devices by improving and optimizing the heat exchanger structure, the geometry design and the operating parameters, because those aspects significantly affect the efficiency of the whole system. The low cost waste heat such as the waste industrial heat, and the waste domestic heat can increase the popularity of thermoelectric technology. Broaden its application fields, such as in energy storage, reduction of heat loading in cars, heat energy management and recovery from manufacturing; it is also necessary for the popularity of thermoelectric technology. Beside of these, the long-term operation and stability assessment is also a research field for scholars.

5. ACKNOWLEDGEMENT

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REFERENCES

Balaji D, Gowrishaknar D, Waste heat harvesting using thermoelectric generator, IOSR journal of engineering, 3 (7), 2013, 01-04.

Byung deok In, Hyung IK Kim, Jung wook Son, Ki hyun Lee, The study of thermo electric generator with various thermal conditions of exhaust gas from diesel engine, International Journal of Heat and Mass Transfer, 86, 2015, 667-680.

Eisenhut C, Bitschi A, Thermoelectric conversion system based on geothermal and solar heat, In: Proc int conf thermoelectric, 2006, 510-5.

Gou X, Xiao H, Yang S, Modeling experimental study and optimization on low-temperature waste heat thermoelectric generator system, Appl Energy, 87, 2010, 3131-6.

Haidar JG, Ghogel JI, Waste heat recovery from the exhaust of low-power diesel engine using thermal electric generators, In Proc int conf thermoelectric, Beijing, China, 2001, 413-7.

Hasebe M, Kamikawa Y, Meiarashi S, Thermoelectric generators using solar thermal energy in heated road pavement, In: Proc int conf thermoelectric, 2006, 697-700.

Hsiao YY, Chang WC, Chen SL, A mathematic model of thermoelectric module with applications on waste heat recovery from automobile engine, Energy, 35, 2010, 1447-54.

La Grandeur J, Crane D, Mazar S, Eder A, Automotive waste heat conversion to electric power using skutterudite, TAGs, PbTe and BiTe, In: Proc int conf thermoelectric Vienna, Austria, 2006, 343-8.

Niu X, Yu J, Wang S, Experimental study on low-temperature waste heat thermoelectric generator, J Power Sources, 188, 2009, 621-6.

Ono K, Suzuki RO, Thermoelectric power generation: converting low grade heat into electricity, J Miner Met Mater Soc., 50, 1998, 12-31.

Rowe DM, Thermoelectrics, an environmentally-friendly source of electrical power, Renew Energy, 16, 1999, 1251-6.

Talom HL, Beyene A, Heat recovery from automotive engine, Appl Therm Eng., 29, 2009, 439-44.

Theresa de Leon M, Harold Chong, Michael Chong, Design and Modelling of SOI-based solar thermoelectric generators, Procedia Engineering, 47, 2012, 76-79.

Yang J, Potential applications of thermoelectric waste heat recovery in the automotive industry, In: Proc int conf thermoelectric Clemson, USA, 2005, 155-9.