Waste Heat Based Power Generation using Thermoelectric Module

G. Prakash, C. Thamotharan and P. Naveenchandran

In recent years, an increasing concern of environmental issues of emissions, in particular global warming and the limitations of energy resources has resulted in extensive research into novel technologies of generating electrical power. Thermoelectric power generators have emerged as a promising alternative green technology due to their distinct advantages. Thermoelectric power generation offer a potential application in the direct conversion of waste-heat energy into electrical power where it is unnecessary to consider the cost of the thermal energy input. The application of this alternative green technology in converting waste-heat energy directly into electrical power can also improve the overall efficiencies of energy conversion systems. In this paper, a background on the basic concepts of thermoelectric power generation is presented and recent patents of thermoelectric power generation with their important and relevant applications to waste-heat energy are reviewed and discussed

Keywords--- *Waste Heat, Electrical Power, Thermoelectric Module.*

I. INTRODUCTION

Our addiction to electricity has generated a concurrent addiction to fossil fuels. However, the reserves of fossil fuels will soon be depleted, since oil is a limited resource. Over the years, the cost of electricity has risen to unprecedented levels due the limited supply of oil and economic and political factors. Thus, renewable energy is a more attractive alternative to electricity generation, as it will also provide a cleaner environment for future generations. In the world today, there are many great solutions to renewable energy, but some are unfeasible. In this project, a device will be created to introduce a way for humans to create renewable energy using thermoelectric devices, which convert the waste heat energy coming out from the exhaust gases into electrical energy.

A. BASIC PRINCIPLE OF THERMO ELECTRIC GENERATOR

A thermoelectric power generator is a solid state device that provides direct energy conversion from thermal energy (heat) due to a temperature gradient into electrical energy based on "Seebeck effect". The thermoelectric power cycle, with charge carriers (electrons) serving as the working fluid, follows the fundamental laws of thermodynamics and intimately resembles the power cycle of a conventional heat engine.

G. Prakash, M.Tech Student, Department of Automobile Engineering, BIST, BIHER, Bharath Institute of Higher Education & Research, Selaiyur, Chennai.

C. Thamotharan, Professor, Department of Automobile Engineering, BIST, BIHER, Bharath Institute of Higher Education & Research, Selaiyur, Chennai.

P. Naveenchandran, Professor & Head, Department of Automobile Engineering, BIST, BIHER, Bharath Institute of Higher Education & Research, Selaiyur, Chennai. E-mail: naveenchandran.automobile@bharathuniv.ac.in

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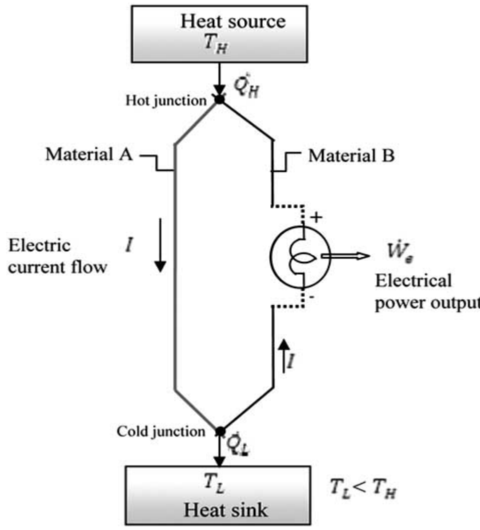

Figure 1.1 Schematic diagram showing the basic concept of a simple

Thermoelectric power generator operating based on Seebeck effect. The basic theory and operation of thermoelectric based systems have been developed for many years. Thermoelectric power generation is based on a phenomenon called "Seebeck effect" discovered by Thomas Seebeck in 1821. When a temperature difference is established between the hot and cold junctions of two dissimilar materials (metals or semiconductors) a voltage is generated, i.e., Seebeck voltage. In fact, this phenomenon is applied to thermocouples that are extensively used for temperature measurements. Based on this Seebeck effect, thermoelectric devices can act as electrical power generators. A schematic diagram of a simple thermoelectric power generator operating based on Seebeck effect is shown in Fig. 1.1. As shown in Fig. 1.1, heat is transferred at a rate of $H_Q$from a high-temperature heat source maintained at $T_H$to the hot junction, and it is rejected at a rate of L_Q to a low-temperature sink maintained at $T_L$from the cold junction. Based on Seebeck effect, the heat supplied at the hot junction causes an electric current to flow in the circuit and electrical power is produced. Using the first-law of thermodynamics (energy conservation principle) the difference between $Q_H$and Q_L is the electrical power output W_e. It should be noted that this power cycle intimately resembles the power cycle of a heat engine (Carnot engine), thus in this respect a thermoelectric power generator can be considered as a unique heat engine.

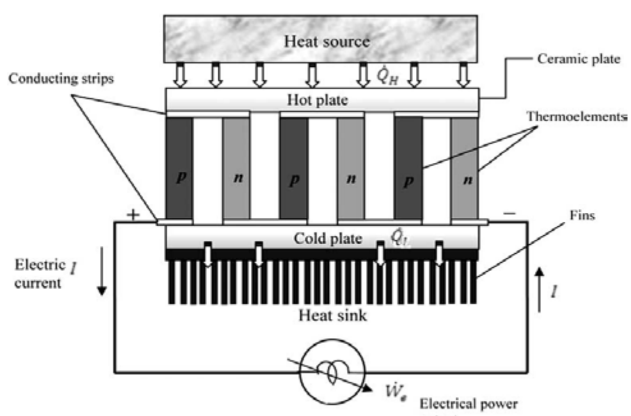

Figure 1.2 Schematic diagram showing components and arrangement of a typical single-stage thermoelectric power generator.

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II. COMPOSITION AND SPECIFICATIONS OF A TEG

Figure 1.**2** shows a schematic diagram illustrating components and arrangement of a conventional single-stage thermoelectric power generator. As shown in Figure 1.2, it is composed of two ceramic plates (substrates) that serve as a foundation, providing mechanical integrity, and electrical insulation for *n*-type (heavily doped to create excess electrons) and *p*-type (heavily doped to create excess holes) semiconductor thermo elements. In thermoelectric materials, electrons and holes operate as both charge carriers and energy carriers. There are very few modules without ceramic plates, which could eliminate the thermal resistance associated with the ceramic plates, but might lead to mechanical fragility of the module. The ceramic plates are commonly made from alumina (Al_2O_3), but when large lateral heat transfer is required, materials with higher thermal conductivity (e.g. beryllia and aluminum nitride) are desired. The semiconductor thermoelements (e.g. silicon-germanium SiGe, lead-telluride PbTe based alloys) that are sandwiched between the ceramic plates are connected thermally in parallel and electrically in series to form a thermoelectric device (module).

More than one pair of semiconductors are normally assembled together to form a thermoelectric module and within the module a pair of thermoelements is called a thermocouple . The junctions connecting the thermoelements between the hot and cold plates are interconnected using highly conducting metal (e.g. copper) strips as shown in Fig. (**2**). The sizes of conventional thermoelectric devices vary from 3 mm2 by 4 mm thick to 75 mm2 by 5 mm thick. Most of thermoelectric modules are not larger than 50 mm inlength due to mechanical consideration.

Waste Heat From Exhaust Gases Generated From Automobiles Applications

The utilization of waste heat energy from exhaust gases in reciprocating internal combustion engines (e.g. automobiles) is another novel application of electricity generation using thermoelectric power generators. Although a reciprocating piston engine converts the chemical energy available in fossil fuels efficiently into mechanical work a substantial amount of thermal energy is dissipated to the environment through exhaust gas, radiation, cooling water and lubricating oils. For example, in a gasoline powered engine, approximately 30% of the primary gasoline fuel energy is dissipated as waste heat energy in the exhaust gases; waste heat energy discharged in the exhaust gases from a typical passenger car travelling at a regular speed is20-30 kW [1]. A comprehensive theoretical study concluded that a thermoelectric generator powered by exhaust heat could meet the electrical requirements of a medium sized automobile.

Industrial Waste Heat Applications

Most of the recent research activities on applications of thermoelectric power generation have been directed towards utilization of industrial waste heat [1]. Vast amounts of heat are rejected from industry, manufacturing plants and power utilities as gases or liquids at temperature which are too low to be used in conventional generating units (<450 K). In this large-scale application, thermoelectric power generators offer a potential alternative of electricity generation powered by waste heat energy that would contribute to solving the worldwide energy crisis, and the same time help reduce environmental global warming.

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Waste Heat from Incineration of Solid Waste Applications

Recently, the possibility of utilizing the heat from incinerated municipal solid waste has also been considered. For example, in Japan the solid waste per capita is around 1kg per day and the amount of energy in equivalent oil is estimated at 18 million kJ by the end of the 21st century. It was reported by [7] that an on-site experiment using a 60Wthermoelectric module installed near the boiler section of an incinerator plant, achieved an estimated conversion efficiency of approximately 4.4%.

MATERIALS USED: As the exhaust chamber is passed with a very high temperature gas of order of 300°C which is coming out from the IC engine and hence the chamber is to made up a material which can withstand a very high temperature, without deforming and hence cold rolled steel sheets are best materials from which the chambers can be build. Other important reason for the use of cold rolled sheets is that it can be easily handled

III. ENGINE USED:

According to our TEG module specifications the hot side temperature of the module should be maintained at 300°C so we use a **4-STOKE SINGLE CYLINDER PETROL ENGINE** which satisfies the temperature requirements.

4-STOKE SINGLE CYLINDER PETROL ENGINE SPECIFICATION:A **petrol engine** (known as a **gasoline engine** in North America) is an internal combustion engine with spark-ignition, designed to run on petrol (gasoline) and similar volatile fuels. It was invented in 1876 in Germany by German inventor Nicolas August Otto. In most petrol engines, the fuel and air are usually pre-mixed before compression (although some modern petrol engines now use cylinder-direct petrol injection). The pre-mixing was formerly done in a carburetor, but now it is done by electronically controlled fuel injection, except in small engines where the ost/complication of electronics does not justify the added engine efficiency.

Fig; 1.5-STROKE SINGLE CYLINDER PETROL ENGINE

The process differs from a diesel engine in the method of mixing the fuel and air, and in using spark plugs to initiate the combustion process. In a diesel engine, only air is compressed (and therefore heated), and the fuel is injected into very hot air at the end of the compression stroke, and self-ignites.

Compression ratio: With both air and fuel in a closed cylinder, compressing the mixture too much poses the danger of auto-ignition — or behaving like a diesel engine. Because of the difference in burn rates between the two different fuels, petrol engines are mechanically designed with different timing than diesels, so to auto-ignite a petrol engine causes the expansion of gas inside the cylinder to reach its greatest point before the cylinder has reached the "top dead center" (TDC) position. Spark plugs are typically set statically or at idle at a minimum of 10 degrees or so of crankshaft rotation before the piston reaches TDC, but at much higher values at higher engine speeds to allow time for the fuel-air charge to substantially complete combustion before too much expansion has occurred - gas expansion occurring with the piston moving down in the power stroke. Higher octane petrol burns slower, therefore it has a lower propensity to auto-ignite and its rate of expansion is lower. Thus, engines designed to run high-octane fuel exclusively can achieve higher compression ratios.

Speed and efficiency: Petrol engines run at higher speeds than diesels, partially due to their lighter pistons, connecting rods and crankshaft (a design efficiency made possible by lower compression ratios) and due to petrol burning faster than diesel. They also tend to have a much shorter stroke and therefore a petrol engines pistons can move up & down much quicker than a diesel engine. However the lower compression ratios of a petrol engine give a lower efficiency than a diesel engine. To give an example, a petrol engine is like operating a bicycle in its lowest gear where each push from your feet adds little energy to the system, but you still expend energy to move your legs back to the TDC position.

Cooling: Petrol engines may be air-cooled, with fins (to increase the surface area on the cylinders and cylinder head); or liquid-cooled, by a water jacket and radiator. The coolant was formerly water, but is now usually a mixture of water and either ethylene glycol or propylene glycol. These mixtures have lower freezing points and higher boiling points than pure water and also prevent corrosion, with modern antifreezes also containing lubricants and other additives to protect water pump seals and bearings. The cooling system is usually slightly pressurized to further raise the boiling point of the coolant.

Ignition: Petrol engines use spark ignition and high voltage current for the spark may be provided by a magneto or an ignition coil. In modern car engines the ignition timing is managed by an electronic unit.

Power measurement: The most common way of engine rating is what is known as the brake power, measured at the flywheel, and given in kilowatts (metric) or horsepower (USA). This is the actual mechanical power output of the engine in a usable and complete form. The term "brake" comes from the use of a brake in a dynamometer test to load the engine.

FABRICATION WORKS: Sheet Metal fabrication is defined as the process of cutting, bending, and assembling the sheet metal. As we need two types of sheet metal chambers 1)heat transfer chamber 2)cooling chamber is to be prepared we use Cold Rolled Steel Sheet metals are used for the chamber body construction.

OBJECTIVES: The main objective of this project is to develop a system using commercially available thermoelectric modules to convert the waste heat which the automotive engines exhaust, into useful electrical energy. This project would be executed at Energy laboratory at department of Mechanical Engineering of MVJ College of Engineering, by installing the thermoelectric generator (TEG) on the exhaust pipe line of variable compression single cylinder petrol engine with a rated speed and rated power of 3000rpm and 2.2 KW respectively. A suitable heat exchanger system would also be developed to house the TEG & the requisite fin surfaces for enhanced heat transfer. A prototype incorporating these features would be designed, manufactured, assembled and tested. Automotive engines reject a considerable amount of energy to the atmosphere through the exhaust gasses.

Significant reduction of engine fuel consumption could be attained by recovering part of exhaust heat by using thermoelectric generators.

IV. METHODOLOGY

CONSTRUCTION: In this section creative engineering design is made.

1) Both IC engine and the Exhaust gas camber are coupled using the nut and bolts and gaskets are provided in order to ensure that no leakage of gas takes place. The outlet of this exhaust gas chamber is connected to the main exhaust line and the gas is let out.
2) A cooling camber is placed on the exhaust gas chamber and it is supplied with cooling water with separate inlet and outlet pipes and the flow rate of the water is controlled.
3) In between these chambers a polyurethane material or glass wool material is used which provides a best insulation so heat doesn't conduct to the cold side.
4) Thermoelectric modules are placed above the exhaust gas chamber such that hot side of the module is faced towards the exhaust as chamber and the cold side of the module faced towards the cooling chamber.
5) Both the chambers are clamped with the help of nuts and bolts and they are tightened with suitable clamping force care should be taken that that clamping force should not exceed the specified value given to the module.
6) A bread circuit is built which consists of the LED's are connected which lit up when the emf will be generated. The LED's may be connected both in series or parallel connections, based on the voltage or current drop to be obtained.
7) Thermocouples are placed on both heat transfer chamber and cooling chambers in order to measure the exhaust gas and cooling water chamber. These thermocouple will acts as the sensors such that they measure the temperatures and give the readings on the digital display units.
8) TEG module wires are made up of Teflon coated so they can withstand a very high temperatures of order of 300°C.
9) These wires are taken out and connected with the bread circuit as well as a multi-meter which reads the voltage and current values generated for different temperatures. Both analog and digital multi-meters can be used for the measurements.

V. DESIGN

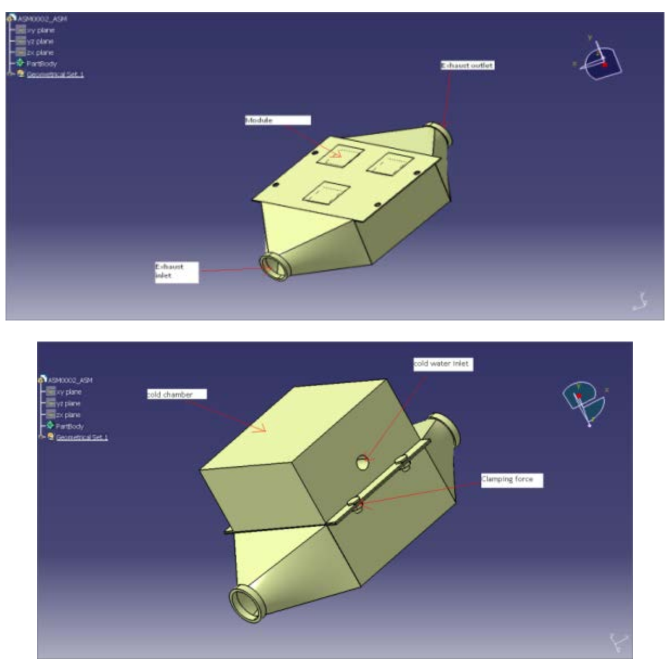


Fig 1.11 CAD DESIGN

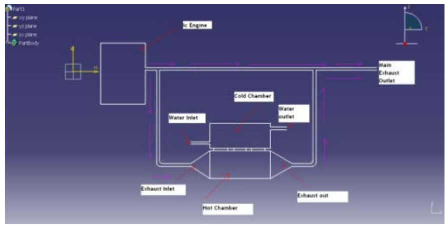


Fig 1.12 CAD Model Section

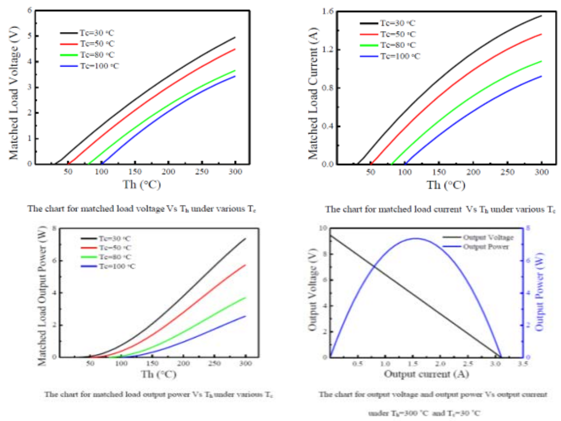
The basic design in our project is as follows:

The exhaust gas coming out from the I C engine is drawn out through a separate pipe set up, and is let in to the Exhaust chamber where the gas is passed through the mesh in order to remove any foreign particles present in the exhaust gas. The thermoelectric modules are placed on the chamber such that when the chamber gets heated up the hot side of the module gets hot at the same time cold side of the module gets cooled for this a separate cooling chamber which is placed on the exhaust chamber will have the continuous water circulation so that the module which is placed in between the chambers gets both heat and cold interface, and when the temperature difference is maximum, hence power output will be the maximum.

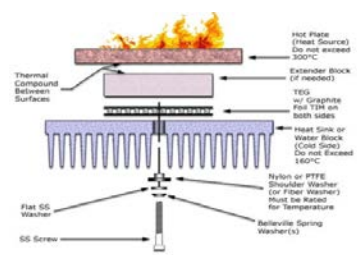
Fig 1.12 Original setup

The thermoelectric module is an electronic device which is embedded with p-type and n-type semiconductors inside. It has both hot and cold sides which are specified on the module itself. The actual dimensions of the TEG module (ZL 2010 1 0193517.9) is 40mmx40mm with 0.5 (+or-) clearances. Two Teflon coated lead wires (AF250) which are emerging out from the modules with negative lead wire (black) and positive lead wire (red) are used for electrical connections . Various performance curves are shown in the below figures. Both the side of the modules are coated with a thin layer of graphite material which has better heat carrying capacities and also the surface of the modules are not evenly smooth it has irregularities so the graphite materials will provide a smooth surface so that it can be placed on modules and uniform heat transfer can be achieved, here the graphite materials acts as “Thermal Interface Material” (TIM) so that helps in proper heat transfer and hence maximum temperature difference with maximum power output can be achieved.

Performance curves of TEG



4.9 TEG MOUNTING:TEGs should be mounted using the compression method. That is, the TEG is compressed between a hot plate and a heat sink that will be cooler. The compression or clamping should be created with stainless steel machine screws on either side of the TEG. See Exploded View and Section View images below.



Exploded View

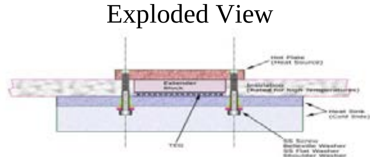


Fig 1.13 Assembled Section View

RESULT AND DISSCUSSION CALCULATION OF HEAT CONTENT OF EXHAUST GASES

Heat supplied(Q)	**112kw**
Heat equivalent to BP	**1.147kw**
Heat carried away by water	**10.46kw**
Heat carried away by exhaust gases	**27.21kw**
Unaccounted losses	**73.184kw**

T_H(^{0}C)	T_L (^{0}C)	ΔT(^{0}C)	VOLTAGE(V)	CURRENT(A)	POWER(W)
270	30	240	4.89	4.08	19.95

VI. EXPERIMENTAL RESULTS

T_H(^{0}C)	T_L (^{0}C)	ΔT(^{0}C)	VOLTAGE(V)	CURRENT(mA)	POWER(W)
110	20	90	2.21	183.9	0.406
120	20	100	2.25	192.1	0.432
130	20	110	2.35	206.3	0.484
140	20	120	2.40	215.4	0.516
150	20	130	2.5	226.4	0.543

Table:

CURRENT & FUTURE DEVELOPMENTS Recently, an increasing concern of environmental issues of emissions, in particular global warming and the constraints on energy sources has resulted in extensive research into innovative technologies of generating electrical power and thermoelectric power generation has emerged as a promising alternative green technology. In addition, vast quantities of waste heat are discharged into the earth's environment much of it at temperatures which are too low

(i.e. low-grade thermal energy) to recover using conventional electrical power generators. Thermoelectric power generation offers a promising technology in the direct conversion of waste-heat energy, into electrical power. Currently, waste heat powered thermoelectric generators are utilized in a number of useful applications due to their distinct advantages. These applications can be categorized as micro- and macro-scale applications depending on the potential amount of heat waste energy available for direct conversion into electrical power using thermoelectric generators. Micro-scale applications included those involved in powering electronic devices, such as microchips. Since the scale at which these devices can be fabricated from thermoelectric materials and applied depends on the scale of the miniature technology available. Therefore, it is expected that future developments of these applications tend to move towards nano technology.

The macro-scale waste heat applications included: domestic, automobiles, industrial and solid waste. Currently, enormous amounts of waste heat are discharged from industry, such as manufacturing plants and power utilities. Therefore, most of the recent research activities on applications of thermoelectric power generation have been directed towards utilisation of industrial waste heat. Future developments in this area might focus onto finding more suitable thermoelectric materials that could handle higher temperatures from various industrial heat sources at a feasible cost with acceptable performance. Another future direction is to develop more novel thermoelectric module geometries and configurations. The developments of more thermoelectric module configurations by developing novel flexible thermoelectric materials will make them more effective and attractive in applications where sources of waste heat have arbitrary shapes.

VII. CONCLUSION

According to my study and came out with following suggestions. This thermoelectric module is fitted in end of the exhaust pipe. The output in this experiment is very low. There is heat loss due to more distance. If the automobile manufactures design the vehicle such way that this thermoelectric module is fitted in the initial stage of exhaust manifold then there is possibility of getting more heat and we can get more power. With this we can easily eliminate the alternator from the car. There is possibility of weight reduction around 1.6 Kg. Alternator weight is around 2.5 kg. Thermoelectric module weight is only 0.8 kg.

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