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# A Review of power generation with thermoelectric system from exhaust of internal combustion engine

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## ABSTRACT

By using the Seebeck effect to produce electrical voltage, thermoelectric as a highly scalable, stationary and silent heat engine has undergone a state of vigorous research. Starting with the review on thermoelectric generators, it shows that thermoelectric is gaining more attention since the past decade. Generally, the research conducted on the thermoelectric generators concentrate on the material development, mathematical and Numerical model development as well as the application of thermoelectric generators. For this article, attention is given to the application research of the thermoelectric generators. From the survey conducted, most of the application research carried out is based on intermittent electrical power generation (e.g. the direct use of solar energy available or waste heat recovery). Hence, it opens an opportunity for the research on the application of thermoelectric generators by utilizing a heat source that is continuously ready for thermal-electrical energy conversion, such as phase change material, geothermal heat or solar pond. In the later section, the review is continued by introducing solar pond, a facility that has been used as a supply of low-grade heat source at the remote area or industrial process heating.. The ultimate idea of this review is to provide an insight that a thermal-storage based heat source (e.g. in this review, the thermoelectric generator) could be useful for small-scale electric power generation, despite its ordinary function as low-grade heat source provider via heat extraction.

Keywords: Power generation, Thermoelectric, Exhaust gases, Internal combustion engine.

## 1. INTRODUCTION

Heat engine: It can be defined as any engine that converts thermal energy to mechanical work output. Examples of heat engines include: steam engine, diesel engine, and gasoline (petrol) engine.

• On the basis of how thermal energy is being delivered to working fluid of the heat engine, heat engine can be classified as an internal combustion engine and external combustion engine.

• In an Internal combustion engine, combustion takes place within working fluid of the engine, thus fluid gets contaminated with combustion products.
– Petrol engine is an example of internal combustion engine, where the working fluid is a mixture of air and fuel.
• In an External combustion engine, working fluid gets energy using boilers by burning fossil fuels or any other fuel, thus the working

fluid does not come in contact with combustion products.

– Steam engine is an example of external combustion engine, where the working fluid is steam.

**Internal combustion engines may be classified as:**

– Spark Ignition engines.

– Compression Ignition engines.

• Spark ignition engine (SI engine): An engine in which the combustion process in each cycle is started by use of an external spark.

• Compression ignition engine (CI engine): An engine in which the combustion process starts when the air-fuel mixture self ignites due to high temperature in the combustion chamber caused by high compression.

– Spark ignition and Compression Ignition engine operate on either a four stroke cycle or a two stroke cycle.

## 2.Thermoelectric generator (TEG)

The use of TEGs as a potential source of for both large scale electric powers as well as an alternative source for low power generation had been delineated by Rowe that presented in his publications [2,3]. From the life cycle analysis conducted, apart from being environmentally friendly, from the economics point of view, the increase in fuel cost will lead to the demand of alternative mean for power generation. The inclusion of externalities consideration will certainly favour the use of TEG as a supplement for electrical energy production [4].

### 2.1. Properties, material, structure, and characteristics

Due to the existence of temperature gradient, the TEG's operation is
based on Seebeck effect and Peltier effect. The former phenomenon, refers to the relation between thermoelectric potential under open circuit condition and the temperature difference is correlated by the
Seebeck coefficient, $\alpha$ (V/K). Hamid Elsheikh et al. [5] in the recent review described the important parameters that govern the performance of the thermoelectric cells. The authors analyse the parameters from the viewpoint of thermoelectric properties and material properties, and extended the discussion on the life expectancy of the thermoelectric cells. They strongly believed that the study on the relation of both electrical and thermal conductivity is the key for improving the performance of thermoelectric cells.

There are different materials available for TEG in order to cater a different range of operating temperature. Different categories of materials had been explored, such as ceramics [6], alloys [7], bulk material [8], complex crystals, oxide materials [9,10], nano-composites. Table 1 summarises the TEG materials, working temperature as well as the *ZT* value of these materials. From Table 1, it is clearly seen that under current development, the BiTe-based material is the most suitable commercially available
material to suit the need of recovering low-grade heat (< 150 °C). Although the TEGs operate base on the temperature difference across its hot and cold junction, there exists a difference in maximum electric power in spite of the fact that the temperature difference across the junction remains constant, sincethe specification of temperature difference gives two degrees of freedom for the values of cold and hot
temperature. Specifically on $Bi_2Te_3$, which operates at temperature < 150 °C, for a fixed

temperature, there exist both upward and downward concavity in the graphs of maximum power versus mean temperature (average of temperatures at the hot and cold junction). In the other words, in order to achieve similar maximum power output, for a given fixed temperature difference, the number of thermoelectric cells needed varies [14]. For the middle and high range of temperature, research had been carried out in the searching and characterisation of new thermoelectric materials [15] and reducing the cost for TEG [10].

## 2.2Mathematical and numerical model development of TEG

In the mathematical modelling of the TEG, often the heat transfer between the TEG and its environment are modelled by Newtonian heat transfer law with the heat transfer rate, $Q$ is directly proportional to the temperature difference, $\Delta T$. In order to take into account the thermodynamics irreversibility of TEG, Chen et al. [16] developed an advanced model of TEG by considering the irreversibility characteristic of TEG. The five heat transfer laws under consideration were Newtonian, linear phenomenological, radiative, Dulong-Petit as well as special complex transfer law. The study showed, external heat transfer model using Newtonian law yield highest efficiency and power output compared the other four heat transfer laws, and external heat transfer models considered will vary working electrical current that results the optimum operating condition of TEG. Besides, Montecucco et al. [17] proposed the solution to the 1-Dimension transient heat conduction equation by incorporating the internal heat generation of TEG. As a result, without fixing the hot side and cold side temperature of the TEG, the transient characteristic of TEG can be evaluated. With the advancement of the computational method, TEG model can be accurately simulated [18,19]. When the TEG is exposed to the heat source with a temperature difference, the device is undergoing transient state before the thermal and electrical dynamically stabilise.

Peltier, Seebeck, Thomson, and Joule are the main effects that taking place in the TEG. Montecucco and Knox [20] modelled the response of TEG under the changing operating condition by using a computer aided model. By taken into account of the important thermoelectric effect such as Joule heating and Peltier effect, the computer model developed will able to predict the TEG response in high accuracy.

Although the model did not include the Thomson effect, however, according to Nguyen and Pochiraju [21], Thomson effect is significant in giving impact on the power generation rather than the thermal behaviour of the TEG.

## 2.3. Recent development on TEGs' application

The TEG can be integrated into various systems, such as, but not limited to heat exchanger system, exhaust gas heat extraction, solar heat extraction, industrial waste heat recovery, or couple with other renewable energy sources, e.g. solar photovoltaic system, forming a hybrid system for better power conversion efficiency as delineated by Kreamer et al. [22]. TEG may also be used for electricity generation for terrestrial application by using optical concentrator and solar absorber with wavelength-selective surface [23] or generating electricity from human body heat with the aid of heat sink [24,25]. Although the use of TEG for remote area power supply is far away to be realised. However, it had been shown from the experimental study that the use of TEG in powering autonomous sensor at the remote area is feasible [26]. The innovative design of heat exchanger for electric power generation using TEG had been conducted. Different design of heat exchanger were considered: (i) roll cake type heat exchanger; a helical flow system, (ii) cylindrical multi-tubes design; including counter flow, parallel flow and isothermal heat exchanger [27–29].

2.4. TEG in solar heat extraction system

As a source of green energy, solar energy can be utilised to generate electricity through the photovoltaic panel, space heating, or solar thermal energy storage via the solar collector. The research on generating electricity with TEG by harvesting the solar energy was mainly conucted base on the concentration of solar radiation in order to achieve higher hot side temperature for higher conversion efficiency.

## METHODS AND MATERIAL

**Thermoelectric Principle of Operation**

Thermoelectricity means the direct conversion of heat into electric energy, or vice versa. According to Joule's law, a conductor carrying a current generates heat at a rate proportional to the product of the resistance (R) of the conductor and the square of the current (I). A circuit of this type is called a thermocouple; a number of thermocouples connected in series are called a thermopile.

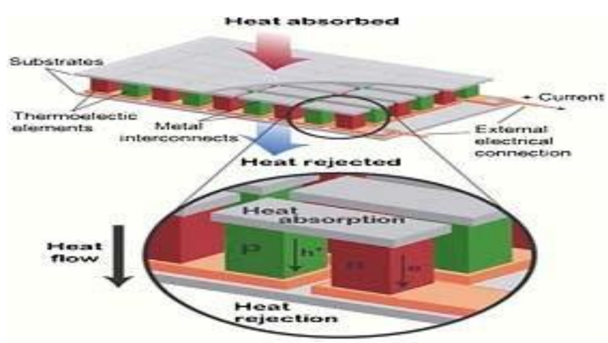


**Figure 1**: Thermionic Principle of Operation

Jean C. A. Peltier discovered an effect inverse to the Seebeck effect: If a current passes through a thermocouple, the temperature of one junction increases and the temperature of the other decreases, so that heat is transferred from one junction to the other. The rate of heat transfer is proportional to the current and the direction of transfer is reversed if the current is reversed.

**Description of the Equipment**

1. **Peltier Module**

A thermoelectric (TE) module, also called a thermoelectric cooler or Peltier cooler, is a semiconductor-based electronic component that functions as a small heat pump. By applying a low voltage DC power to a TE module; heat will be moved through the module from one side to the other. One module face,

**Figure 2:** Peltier Module

**2. TE- Generator**

Based on the Seebeck effect, thermoelectric devices can act as electrical power generators. A schematic diagram of a simple thermoelectric power generator operating based on Seebeck effect.

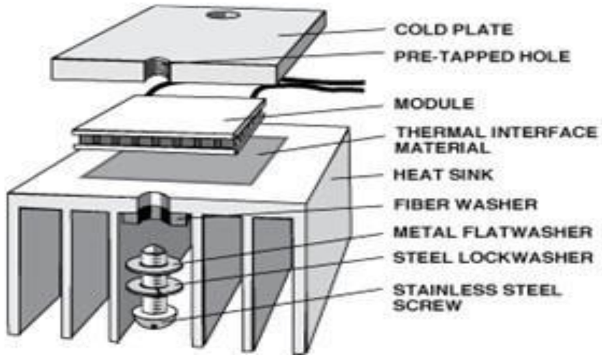


**Figure 3:** TE-Generator

**3. Thermal Grease**

Thermal grease (also called thermal gel, thermal compound, thermal paste, heat paste, heat sink paste or heat sink compound) is a viscous fluid substance, originally with properties akin to grease, which increases the thermal conductivity of a thermal interface by filling microscopic air-gaps present due to the imperfectly flat and smooth surfaces of the components; the compound has far greater thermal conductivity than air (but far less than metal). In electronics, it is often used to aid a component's thermal dissipation via a heat sink.

**4. Booster Circuit**

**Figure 4:** Booster Circuit

This is based on the theory that inductor holds current and passes in opposite direction. This is a DC to DC converter and it has a poor efficiency of 60-80%. So we can't use it for a large project. We can use it for low power consuming models like 12 V and 3 V models which requires 250 mA current. We have to spend 650 mA with 80% efficiency. In this circuit we are going to put DC pulse of around 2V through TEG and amplifying to 12 V as output. We need to fallow the below for expected voltage range. 6 V to 12 V @1 A: 80 turns of 24swg wire in a 0.5 mm ferrite core.

6 V to 12 V @500 mA: 60 turns of 36swg wire in a 0.5 mm ferrite core

The main purpose of using the Booster Circuit is to amplify the voltage obtained from TEG. From TEG we can get a maximum of 2V and 500mA current. The Booster circuit will amplify the voltage to 12V and there is a digital display is provided in it which can display the amplified voltage.

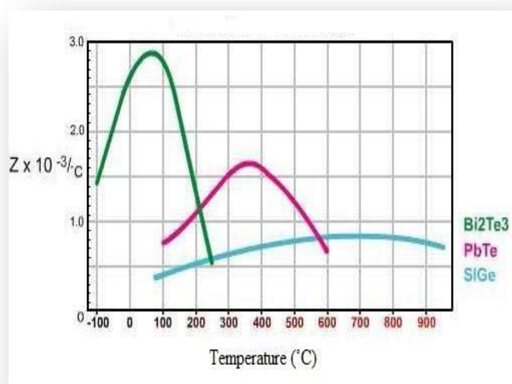


**Figure6:** Performance of Thermoelectric Materials at various temperatures

The figure of merit Z describes material performance. It depends on the thermoelectric material properties.

Where, α =Seebeck coefficient, σ = electrical conductivity, k = thermal conductivity.

Single pair of thermoelectric couple contains one p and n type of semiconductor legs and a module has number of couples electrically connected in series and thermally in parallel. The enclosed parallel plates are made up from ceramic substrate which is electrical insulators.

**(ii) Heat source and heat sink:**

- A heat source is an object that produces or radiates heat.
- 1)Copper heat source

**Figure 5** Copper heat source fabricate for the present study

Copper has the high thermal conductivity and melting point easy to weld at silencer bend pipe which transmit heat to the thermoelectric generator. Therefore in this experimental setup, copper plate as a heat source at hot side is used. The hot junctions of the TEGs are connected to the copper plate needed to the bend pipe of I.C. engine carrying the hot exhaust gases. This copper plate have a smooth surface and dimensions 185mm x75mm x6mm acts as a heat source.

- A heat sink is an object that absorbs and dissipates heat from another object using thermal contact.

**DESIGN CALCULATION**

**1) 1 Specification of Petrol Engine**

| | |
|---|---|
| Type | Two stroke |
| Cooling System | Air cooled |
| Bore/Stroke | 50 X 50 mm |
| Compression Ratio | 98.2 cc |
| Piston Displacement | 6.6 : 1 |
| Maximum Torque | 0.98 kg-m at 5500RPM |

**2) 2 Calculation for Voltage generated**

From the equation of Seebeck effect,

$$V = \alpha\ (Th - Tc)$$

Where,

V – Voltage Generated in Volts α – Seebeck coefficient in μV/K $T_h$- temperature of hot surface (silencer) in Kelvin $T_c$-temperature of cold surface (atmosphere) in Kelvin α of Bismuth Telluride - 287μV/K

$T_c$ = 303 k

A few temperatures of the hot silencer is taken into consideration and the corresponding voltages that are expected to be generated according to the Seebeck equation

Is calculated as follows,

$$V = \alpha (T_h - T_c)$$

*Case 1:*

$T_h$= 403 k

V= (287 *10$^{-6}$)* (403-303)

= (287 *10$^{-6}$)*(100) = 0.0287 V Case 2:

$T_h$= 453 k

V = (287 *10$^{-6}$)* (453-303)

= (287 *10$^{-6}$)*(150)

= 0.04305 V

These voltages are meager in value .This can be boosted up using the booster circuit. The experimental results obtained are tabulated as follows:

| Temperature difference δt (k) | Voltage without boosting (volt) | Voltage after boosting (volt) |
|---|---|---|
| 80 | 0.02296 | 1.44 |
| 100 | 0.02870 | 2.53 |
| 120 | 0.03444 | 3.21 |
| 140 | 0.04018 | 3.85 |
| 150 | 0.04305 | 4.43 |
| 160 | 0.04592 | 4.94 |
| 180 | 0.05166 | 5.37 |
| 200 | 0.05740 | 6.10 |

**Table I:** Voltage generated and boosted for different temperatures

## CONCLUSION

In this project we have successfully fabricated an exhaust gas heat recovery power generator. Thus the eco-friendly power generation method can be implemented for domestic and commercial use at an affordable cost. The efficiency of the engine will not be affected because only the surface heat of the silencer is drawn out. The main objective of this paper is to recover the surface exhaust heat to avoid the accidents (Burn-outs) caused by the overheated silencers, and to convert the recovered heat to useful electric energy. This objective has been successfully accomplished in this paper. The output could be increased by connecting a number of TEGs in series, so that the voltage gets added up leading to increased power. The energy produced from this system could be used to power any auxiliary devices in an automobile directly or it could be stored in a battery and then used later.

1. This project aims to find a possible way to recover the waste heat from the exhaust of I.C. engine as well as to design and fabricate one such system to serve the aim.

2. Experimentally it is found that when two thermoelectric generators are connected in series. This generated power either directly used to run some auxiliary devices of an automobile or may be stored in the battery and used later.

3. These auxiliary loads can be supplemented from battery to this system thereby reducing load on alternator.

4. The study also investigates the effect of engine speed on temperature difference and voltage generated.

5. The engine performance is unaffected by the designed system because heat extracted from the surface of the bend-pipe of the exhaust manifold which does not affected the working of engine.

6. If higher temperature range is required then TEG module must be changed to higher temperature range (200°C). Thus, the above stated system may be successfully implemented in different automobile engines, with slight changes.

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