

# Effect of Using the Thermoelectric Exhaust Energy Recovery System on the Vehicle Emission

Mohamed Khalil

**Abstract**—In recent years, the world interested in how to use the lost energies of vehicle engines, especially the exhaust energy. The engine exhaust has tremendous amount of energy that can be recovered by waste heat recovery systems. The thermoelectric concept is seen as an efficient solution for recovering waste heat from engine exhaust and converts in to electric energy. In this paper, the effect of using the waste heat recovery system on the engine emission will be investigated. From the results, we can say that the engine emission will be improved by using proposed technique.

**Index Terms**— Engine emission, thermoelectric generator, waste heat energy, waste heat recovery system, exhaust gases, opacity

## 1 INTRODUCTION

In recent years all the world interest with the environmental and energy issues has brought in major interests to the research of advanced technologies particularly in highly efficient internal combustion engines, that due to the decrease in the level of crude oil in the world. From view the socio-economic perspective, as the level of energy consumption is directly proportional to the economic development and total number of population in a country, the growing rate of population in the world today indicates that the energy demand is likely to increase [1], [2]. Thermal energy generated by internal combustion engines are very large and are considered undesirable energy because of its adverse effects on the environment. Two-thirds of the energy from combustion in a vehicle is lost as waste heat, of which 40% is in the form of hot exhaust gas [3], [4]. The thermoelectric generators (TEG) able to recover some of this waste energy from the exhaust heat, and from previous researches in this field, that a sure improving fuel consumption by as much as 5% by using this technology [5]. From the latest developments and technologies on waste heat recovery of exhaust gas from internal combustion engines (ICE), these include (TEG), Organic Rankine cycle (ORC), six-stroke cycle IC engine and new developments on turbocharger technology [6]. 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".

Early 19th century scientists, Thomas Seebeck and Jean Peltier, first discovered the phenomena that are the basis for today's thermoelectric industry. Seebeck found that if you placed a temperature gradient across the junctions of two dissimilar conductors, electrical current would flow. On the other hand, Peltier found that by passing the current through two dissimilar electrical conductors that causes heat to be either emitted or absorbed at the junction of the materials. By advancements in semiconductor technology, the practical applications for thermoelectric devices became feasible. With modern techniques, the thermoelectric modules that deliver efficient solid state heat-pumping for both cooling and heating can be produced; many of these units can also be used to generate DC power in special circumstances (i.e., conversion of waste heat).

In general, There are many papers studied the effect of using the TEG on the vehicle fuel consumption and reached to can save about 5% from the fuel consumption in an internal combustion engine [5], [6]. This saving comes from taking advantage of electric power generated from these cells and using a smaller alternator to reduce the load on the engine. This means reducing in the exhaust gases emission from an ICE. In this paper, we will illustrate additional feature for the TEG cell on the opacity value for diesel ICE. To illustrate the effect of these cells on the opacity value of the exhaust, so we will use an original alternator and don't take advantage of the energy generated from these cells to see impact it (i.e. don't use the cell for saving the fuel consumption, used only for studying the effect it on the opacity emission).

• Mohamed Khalil is currently Associate Prof. in Faculty of Engineering-Matara, Automotive & Tractor Engineering Dept., Helwan University, Cairo, Egypt. Email: mohamedibrahim71@yahoo.com

## 2 BASIC THEORY OF A THERMO-ELECTRIC GENERATOR

The basic theory of the TEG is based on a phenomenon called "Seebeck effect" that depends on a temperature difference between the hot and cold junctions of two dissimilar materials to generate a voltage, i.e., Seebeck voltage. Indeed, this phenomenon is used to thermocouples that are extensively used for temperature measurements. So we can be used the thermoelectric devices as electrical power generators, based on the Seebeck effect

The following schematic diagram in Fig. 1 illustrates a simple thermoelectric power generator operating based on Seebeck effect. The heat is transferred by a rate of  $Q_H$  from a high-temperature heat source maintained at  $T_H$  to the hot junction, and it is rejected by a rate of  $Q_L$  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 [1].

## 3 COMPOSITION OF A THERMO-ELECTRIC GENERATOR

Figure 2 shows a schematic diagram illustrating components and arrangement of a conventional single-stage thermoelectric power generator. As shown in Figure 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.

## 4 AUTOMOTIVE APPLICATION OF THE THERMOELECTRIC GENERATOR

Ref [7] is considered from the first researchers that tested the TEG technology in automotive waste heat recovery, followed by tests on modified vehicle engines such as a Porsche 944 [8], Cummins Turbo-diesel engine truck [8], [9], a GM Sierra Pickup Truck [10] and others, more recent works [11], [12], [13], [14], but in most cases the potential for power recovery is just enough to meet the electric demands of the various electrical accessories. However, reputable studies indicate that, if the system is properly designed, it should be possible to recover a significantly higher amount of energy [15], [16], when adding the combined potential of the cooling system, lubrication system and exhaust system. All of these TEGs used exhaust gases and engine coolant as the heat source and sink, respectively.

Other researchers at BMW obtained 200 W of electrical power from a TEG, while General Motors noted that achieving 350 W and 600 W is possible in a Chevrolet Suburban under city and highway driving conditions, respectively. On the other hands, A diesel engine TEG application modeled by [17], [18] demonstrated a highly efficient thermoelectric stack composed of segmented legs and achieved a 5% to 10% efficiency depending on engine operating conditions.

## 5 EXPERIMENTAL SETUP

The test is carried out a diesel engine at the research lab of Automotive Engineering Dept., Faculty of Engineering-Mataria, Helwan University. The experimental setup is shown in Figure 3, and the specification of the used engine that was used in the test rig will be stated in the following Table 1. The exhaust system is modified by adding a tube after the exhaust manifold to fix the Thermoelectric Generator TEG cells on it. The cross section of the used tube is square (40x40)mm. The no. of TEG cell that are used in the experimental work as shown in Figure 4 are 10 cells and the specification of this cell is (40x40x3.1mm, 71 junctions, 24A, 8.5V) mm. These cells are fixed on the squared tube as a five cells on opposite sides. We used the Smoke Opacity Analysis for Brain Bee Company (Model OPA-100). The Technical data of this device is presented in Table 2

## 6 RESULTS AND DISCUSSION

The opacity value of the exhaust is measured at different engine speeds and at different engine load by using smoke opacity meter. These measurements are taken once when activated the TEG cell and another time with without activation of the TEG cells that are installed on the exhaust pipe at the same conditions.

The results that are presented from Fig. 5 to Fig. 7 illustrate effect the opacity value versus engine speed at different engine load. Through these figures, we can say that the opacity value is improved slightly when activating the TEG cells and this relationship can be applied on all engine speeds.

On the other hand, we present the results by comparison the opacity values under different engine load at different engine speed as shown in Fig 8 and Fig 9. These figures show that the opacity value not only increases with increasing of the engine load but also increases with the engine speed. This relationship is applied Whether the TEG cells has been activated or not.

The opacity improvement percentage is calculated and drawn as shown from Fig 10 to Fig. 13. These figures show that the rate of opacity improvement increases with engine partial load to a certain level and then decreased with increasing load.

From the previous results, we can explain this phenomenon as the following. When activating the TEG cells that are installed on the exhaust pipe, the exhaust temperature will be absorbed by these cells to generate the electric energy. The absorbed temperature from the exhaust air will reduce the excitation existence in it. This reduction in exhaust temperature will premise to some of the particulate of the carbon staying inside the exhaust pipes without exit. On the other hands, when the Engine speed increases about a certain value according to the engine load that causes excitation the exhaust gases and help to increase the opacity value and reducing the opacity improvement. No one can deny that the use of these cells will positively affect the atmospheric temperature, where they absorbs the amount from the exhaust heat to turn it into electrical energy and then reduce the heat energy emitted from the engine to the atmosphere.

## 7 CONCLUSION

- The opacity value emission depends on the engine speed and engine load
- Using of the TEG cells improves the opacity value emission with different degrees according to the engine speed and engine load.
- Getting the experimental equations representing the opacity improvement according to each of the engine speed and engine load.
- The atmospheric temperature will be reduced by using the TEG cell on the exhaust pipe where it will reduce the exhaust gas temperature by convert the exhaust temperature to electric power

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TABLE 1  
ENGINE SPECIFICATIONS

Model	Isuzu 4HF1
No. of Cylinder	4 in line, OHV
Fuel type	Diesel
Bore x Stroke (mm)	112 x 110
Engine Capacity (cc)	4334
Compression Ratio	19.0 : 1
Max power	76 kW @ 3000 rpm
Max torque	242 Nm @ 2000 rpm



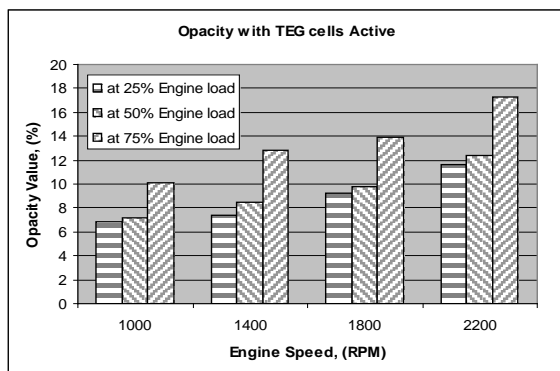


Fig 8 Opacity value versus engine speed when TEG cells are active

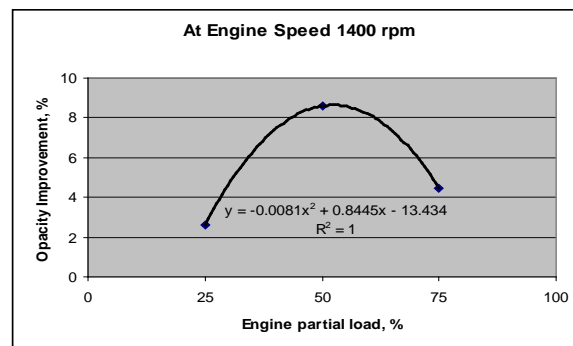


Fig 11 Opacity Improvement versus the Engine Partial load at engine speed 1400 rpm

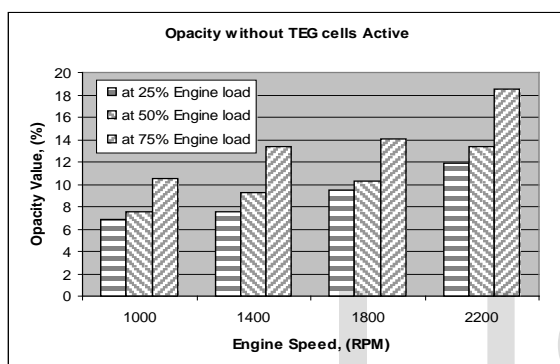


Fig 9 Opacity value versus engine speed when TEG cells are not active

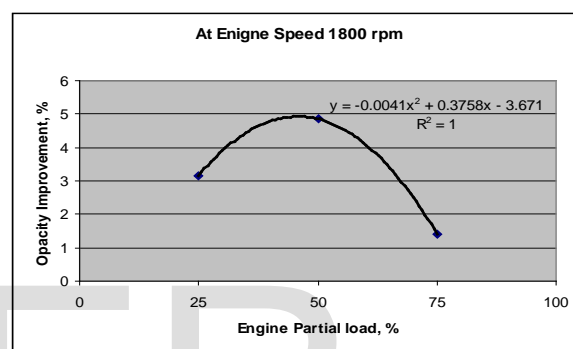


Fig 12 Opacity Improvement versus the Engine Partial load at engine speed 1800 rpm

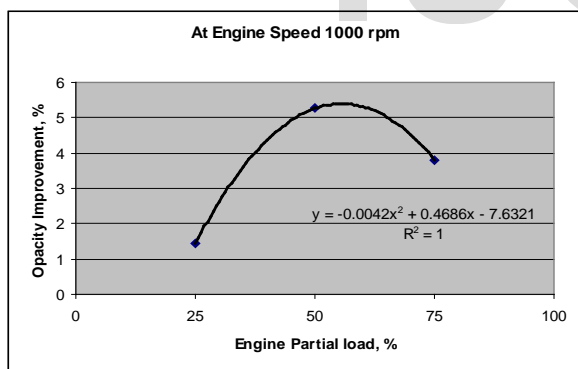


Fig 10 Opacity Improvement versus the Engine Partial load at engine speed 1000 rpm

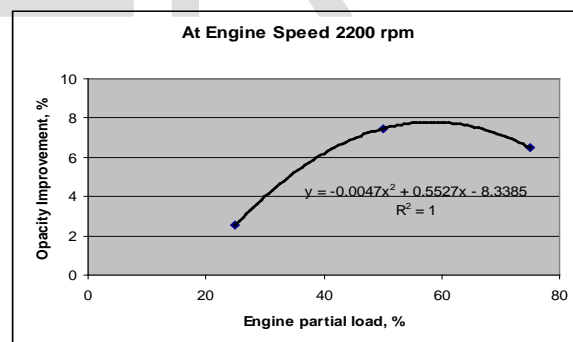


Fig 13 Opacity Improvement versus the Engine Partial load at engine speed 2200 rpm