

Chapter 15

Thermoelectric Conversion of Engine Cylinder Heat into Electric Energy



Mohamad Shukri bin Mohd Zain, Ahmad Kamal bin Ismail, Khairul Shahril bin Shaffee, Khairul Akmal bin Shamsuddin, Tajul Adli bin Abdul Razak, and Sharzali bin Che Mat

Abstract In an automobile, the internal combustion engine (ICE) does not efficiently convert heat into useful energy. A majority of this heat is expelled out as waste heat. This paper focuses on the recovery and utilization of waste heat into useful electrical energy by converting heat from the engine cylinder head surface directly into electrical energy by using thermoelectric generator (TEG). TEG has two distinct sides, referred to as the hot and cool sides, respectively. When the hot side of the TEG is heated while the cold side is chilled, the TEG is able to generate voltage as a result of the temperature difference. The boost converter boosts the electric potential produced by the TEG thereby increasing the magnitude of voltage required to supply energy to the load. The circuit is connected to the LED light as a load. The results were concluded that temperature difference is the most important factor in obtaining the appropriate voltage.

Keywords Engine cylinder head · Thermoelectric generator · Peltier plate · Seebeck effect · Heat energy

M. S. M. Zain (✉) · A. K. Ismail · K. S. Shaffee · K. A. Shamsuddin · T. A. A. Razak
Universiti Kuala Lumpur, Malaysian Spanish Institute Kulim Hi-Tech Park, 09000 Kulim, Kedah,
Malaysia
e-mail: mshukrimz@unikl.edu.my

A. K. Ismail
e-mail: ahmadkamal@unikl.edu.my

K. S. Shaffee
e-mail: khairuls@unikl.edu.my

K. A. Shamsuddin
e-mail: khairulakmal@unikl.edu.my

T. A. A. Razak
e-mail: tajuladli@unikl.edu.my

S. C. Mat
School of Mechanical Engineering, College of Engineering, Cawangan Pulau Pinang, Universiti
Teknologi MARA, Kampus Permatang Pauh, 13500 Permatang Pauh, Pulau Pinang, Malaysia
e-mail: sharzali.chemat@uitm.edu.my

15.1 Introduction

The need toward energy is growing by the day, yet there are only few sources available to produce energy as our fuel reserves deplete. Waste heat energy must be utilized in some way. Waste heat can be collected and recycled into useful work using several devices that execute waste heat recycling. Most of the waste heat recovery systems are built in the form of thermal energy, which is then transformed into electricity. The thermoelectric generator (TEG) module is used to efficiently produce energy from waste heat by direct conversion of temperature difference to electric voltage (Gajabe et al. 2018). This study aimed to obtain the heat produced from engine and investigate the effect of the temperature difference between cylinder head and cold region toward performance of voltage by doing an experiment on the cylinder head. The engine cylinder head was the upper part of engine and closes of combustion chamber. The result between voltage and current as a function of temperature difference was obtained in the study. The reading was taken by measuring the temperature at hot region from cylinder head and cold region cooling plate.

15.2 Literature Review

This section focused on the other study reviews that were useful to assist in identifying and considering the method to measure and record the data that were obtained from experiment to improve the performance of the TEG.

15.2.1 Heat Energy

The heat is the form of energy that is widely used in our daily life. The example of heat energy can be found in compressors, internal combustion engine, and other various equipment. In the heat energy, the heat flows between two materials of different temperatures which from the hot surface to the cold surface. The heat can transfer via conduction and radiation or in convection. The heat quantity is measured in terms of Joules (J) in SI units. The magnitude of heat generated at various sources is different; thereby, the temperature of these operating equipment is not the same and hence produces power of different ratings (Venkatesh et al. 2019). All devices under the heat energy follow the laws of thermodynamics including heat engine and heat pump.

15.2.2 Thermoelectric Generator

Thermoelectric power is created when heat energy is converted to electrical energy. This temperature difference causes carrier spread and generates electric current, when the temperature difference between two conductors is large enough, the electrons flow from the hot junction area to the cold junction region (Venkatesh et al. 2019). As a result, electromotive force exists. This process is referred as the Seebeck effect, and the potential difference that occurs during this time period is referred to as the Seebeck voltage (Shu et al. 2012).

The Seebeck Effect and Thermoelectric Module are shown in Figs. 15.1 and 15.2, respectively. Thermoelectric generators are solid-state devices which primary purpose is to convert heat directly to electricity or to convert electrical energy to thermal energy for heating and cooling. This defines that the thermal electron moves from hot junction region to cold junction region. Thus, the electromotive force (emf) is produced in the thermoelectric module directly proportional to the temperature difference (Sunawar et al. 2017). Temperature difference can be stated as Eq. 15.1 below.

$$\Delta T = T_h - T_c \quad (15.1)$$

TEG is often composed of many thermopiles linked in series to maximize the output power (Kamal et al. 2013). Each Peltier plate is composed of several thermocouples (TC) linked in series electrically and thermally. The thermocouple is constructed from two materials with diametrically opposed Seebeck coefficients. Due to Seebeck effect, the appearance of a temperature gradient, ΔT (Eq. 15.1), and

Fig. 15.1 The Seebeck effect

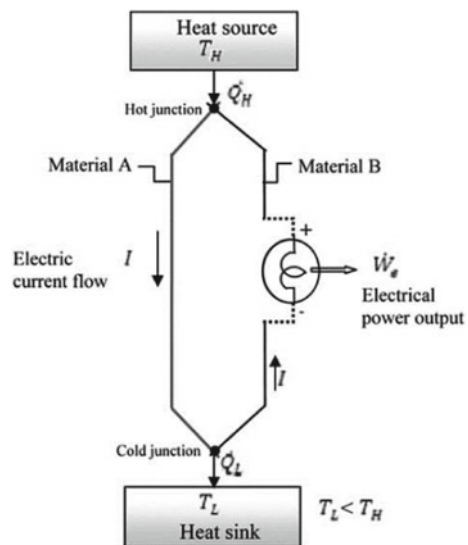
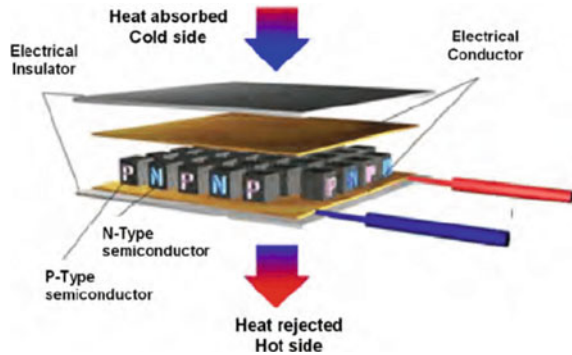


Fig. 15.2 The thermoelectric module



then the voltage can be stated in Eq. 15.2 below.

$$V_{\text{out}} = N\alpha_{\text{AB}}\Delta T \quad (15.2)$$

The TEG is composed of thermocouple pairs of n-type and p-type semiconductor materials. These are electrically coupled to produce a thermopile array consisting of several thermocouples placed between thin ceramic wafers. TEG equipped with liquid on the cold side outperforms all other cooling methods and generate much more net extra power.

15.3 Methodology/Experimental Setup

15.3.1 Experimental Setup

The experiment was conducted on the actual running motorcycle engine (Fig. 15.3) and also laboratory setup. The motorcycle temperature data were observed based on three riding modes such as idle, heavy traffic, and highway ride. The motorcycle operating temperature data were recorded in Table 15.1 as a reference of control temperature for laboratory setup.

The schematic diagram in Fig. 15.4 is designed for the laboratory setup in order to convert heat energy into electric energy. The laboratory design is separated into two parts, the first part is the heat source using IKA hot plate and the second part is the circuit system which consist of a switch, step-up boost converter, and LED light with different power, 1 W and 3 W, respectively.

Figures 15.5 and 15.6 show the photograph of the experimental setup. In the laboratory experiment, the IKA hot plate was heated up with the cylinder head cap and circuit connected to Peltier plate using thermal conductive paste. The standard performance Peltier plate TEC1-12705 has been used as the main part in power

Fig. 15.3 Measurement of engine cylinder head temperature



Table 15.1 Engine cylinder head operating temperature

Riding mode	Average speed (km/h)	Running temperature (°C)	Surrounding temperature (°C)	Difference temperature (°C)
Idle	0	61	32	29
Highway	110	104	37	67
Heavy traffic	15	133	38	95

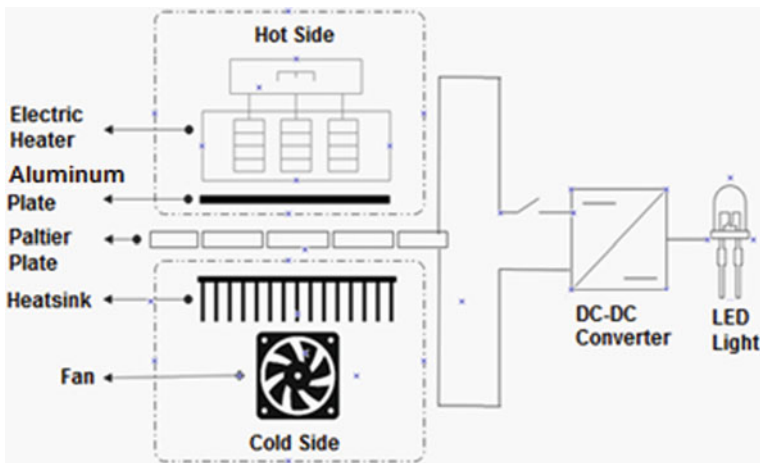


Fig. 15.4 Schematic diagram for laboratory setup

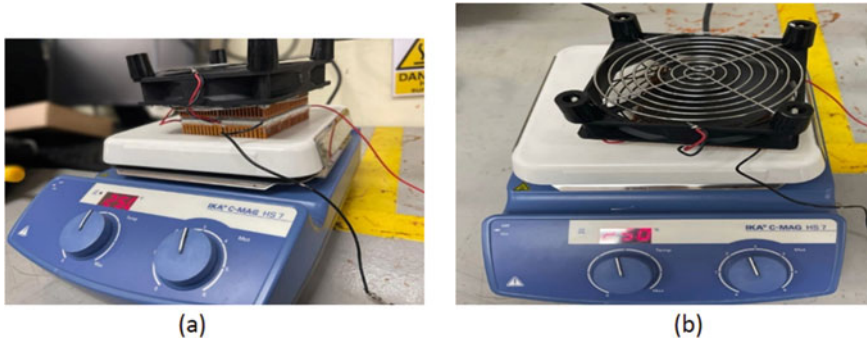
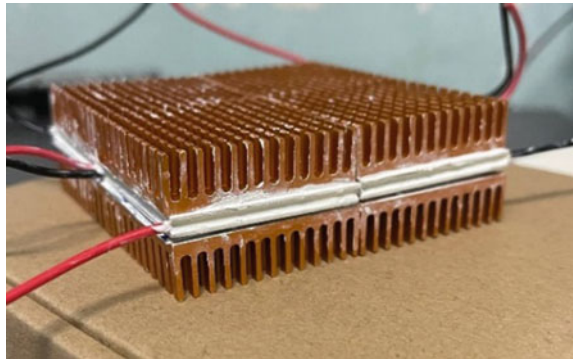


Fig. 15.5 Experimental setup **a** Front view. **b** Top view

Fig. 15.6 Bottom view of experimental setup



generation system. The physical dimensions of the Peltier plate are $40 \text{ mm} \times 40 \text{ mm} \times 3.8 \text{ mm}$ for the width, length, and thickness, respectively.

The Peltier plate then converts the heat energy into electrical energy according to different temperatures set by experiment. After the temperature rises, these electrical energies are then being stored in step-up boost converter. The boost converter works like a battery to store energy and release them at a certain period with the desired amount of current needed. The boost converter is a fast-charging and slower-discharging capacitor than other types of capacitors. The super-capacitor output is given to the boost converter. The boost converter is a type of DC-to-DC converter. The function of boost converter is to convert the output voltage higher than the input voltage. The boost converter output is given to the LED light acting as the load as well as the indicator toward current flow as shown in Fig. 15.7. In this project, the signal of the input and output power to maintain the constant output power is achieved with the help of boost converter.

The TEG device is directly connected to the booster converter. The voltage flow from TEG to booster converter and the wires are related to TEG, switch, and boost converter. An ON/OFF switch is fixed and directly connected to the load. When the switch is ON, the voltage directly passes to the load. In the boost converter, there is a

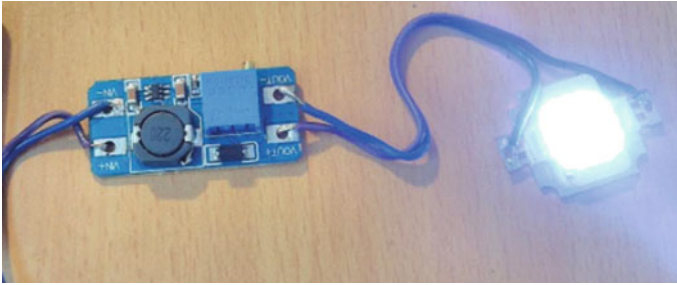


Fig. 15.7 Circuit system

resistor that minimizes the voltage and is directed to LED light. LED light emits that indicates the current is passing. The voltage flow capacity of the load is recorded. Four TEG were electrically connected in series, and thermally conductive silicone was used to adhere them to the aluminum surface as the hot side.

As a result, the energy from the engine cylinder head waste heat can be transferred to TEG and then transferred to the boost converter which controlling the terminal voltage. TEG would help to improve efficiency of engine cylinder head by absorbing and flow it to the electric circuit to produce useful energy. After the heat was supplied to the load, the input and output voltage is taken by using digital multimeter. The data collected is transferred to the table to plot the graph.

15.4 Result and Discussion

The experimental results are shown in Figs. 15.8 and 15.9. Figure 15.8 shows the data of output voltage and current from TEG system. Based on the graph, the higher value of the voltage and current was Voltage2-1W LED load and Current2-1W LED load, respectively. It was found that the output voltage and current increased with the temperature difference regardless of the amount of load. Besides, the output voltage and current were found to decrease by increasing the load.

Figure 15.9 describes that the output power increased with the temperature difference increased. Based on the graph, the higher value of the power was Power2-1W LED. The temperature difference increased due to the high amount of temperature that was supplied to the system. In addition, the output power was found to increase by reducing the load.

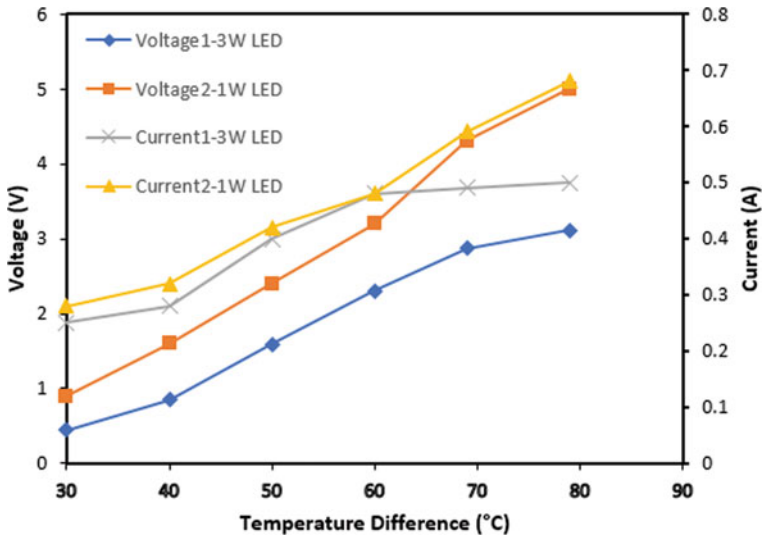


Fig. 15.8 Graph of output voltage and current with 1 and 3 W LED light versus temperature difference

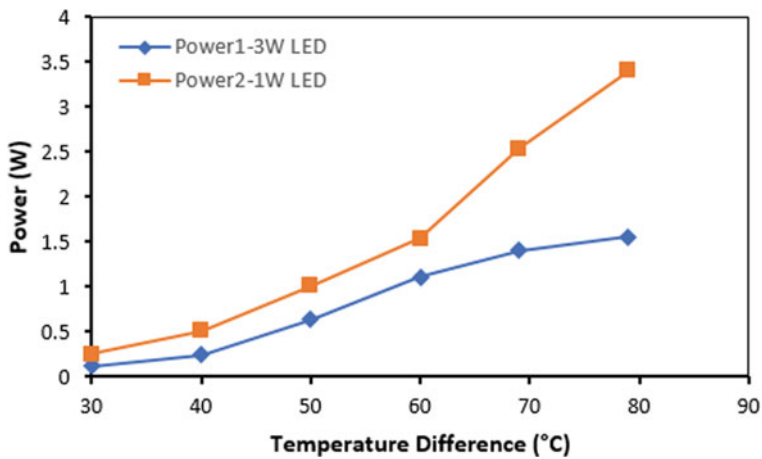


Fig. 15.9 Graph of output power with 1 and 3 W LED light versus temperature difference

15.5 Conclusion

In this paper, the power generation system of a cylinder head waste heat has been studied using TEGs. The output voltage and current have been examined as a function of temperature difference with two different load settings which are 1 and 3 W LED light. It is clear that the output voltage and current increased with the temperature

difference regardless of the amount of load. In addition, the power output was found to decrease by increasing the load. The waste heat of cylinder head that was harvested from TEGs and then converted to electricity can be utilized for low-power unit applications.

References

- Gajabe MKA, Dhanke MKP, Tikhe SJ (2018) A review on utilization of waste heat from automobile based on thermoelectric generator. *International Research Journal of Engineering and Technology (IRJET)* 5(2):469–471
- Kamal A, Zulki M, Zubair M, Ari Z (2013) Application of porous medium burner with micro cogeneration system. *Application of porous medium burner with micro cogeneration system. Energy* 131–142
- Shu G, Zhao J, Tian H, Liang X, Wei H (2012) Parametric and exergetic analysis of waste heat recovery system based on thermoelectric generator and organic Rankine cycle utilizing R123. *Energy* 45(1):806–816
- Sunawar A, Garniwa I, Hudaya C, Generator AT (2017) The design of alternative electric energy utilizes solar heat in the vehicle cabin with thermoelectric module. *International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*. <https://doi.org/10.1109/ICHVEPS.2017.8225928>
- Venkatesh A, Nazar Ali A, Jaiganesh R, Indragandhi V (2019) Extraction and conversion of exhaust heat from automobile engine in to electrical energy. *IOP Conference Series: Materials Science and Engineering* 623(1):52–57