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Application of Thermoelectric Generator in Incinerator

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Abstract

Thermoelectric generator (TEG) is an alternative energy that converts waste heat into electricity through a thermoelectric device (TED), which requires different temperatures between its hot and cold sides. They offer an attractive power generation option. They have no moving parts, are robust and emit no pollutants. The power generated by the thermoelectric (TE) system is almost directly proportional to the temperature difference between the hot and the cold sides. The main problem of the TEG is the cold side involving a cooling system. This work explores the efficiency of TEG added in community garbage incinerator (CGI), where the cooling system with and without water are compared. The two-hundred-liter incinerator was fabricated with twenty-four-TEG devices by series. In the water-cooling system, the Stirling engine was fabricated as the cooling system and in an experiment, the CGI was performed for 30 min. Also, the voltage-output (V_{out}) was measured and averaged ten times. We found that the maximum V_{out} open circuit value of 20.71 V was obtained at temperature value of 67.70 °C. The calculated efficiency is 23.94% for the heat-sink cooling system and enhanced to 47.30% for Stirling engine cooling.

Keywords: Thermoelectric generator; Stirling engine; Communication garbage incinerator

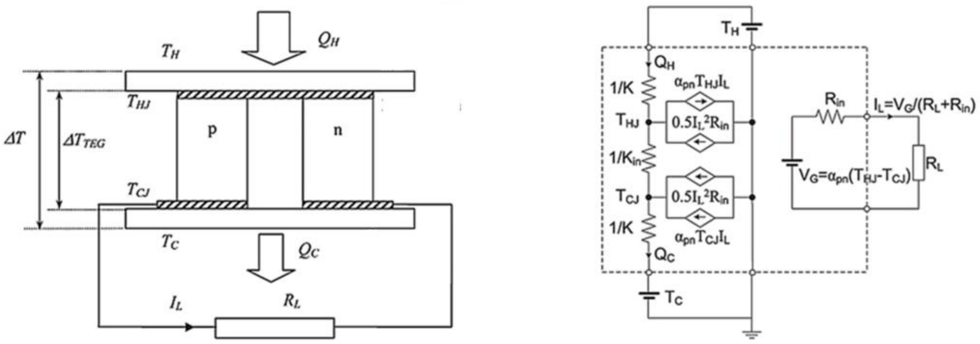
Introduction

Incineration is an effective method that reduces the solid waste up to 70 – 90% [1]. It is the main waste-to-energy form of treatment and a treatment technology that involves the destruction of solid waste by controlled burning at high temperatures and is usually accompanied by the release of heat. Essential factors considered in the reduction of pollution are the design and construction of municipal solid waste incinerator; municipal solid waste incinerator is easy to use. Danrongsak et al., [2] reported that the designed work of CGI combustion rate designed and constructed in the municipal solid waste incinerator to produce electricity using the thermoelectricity to convert waste heat from combustion to be beneficial does not exceed 30 kg h^{-1}. Therefore, the thermoelectricity generating electricity from heat is an interesting technique, and is applied to renewable energy [3]. Zhang et al., [4] reported that to produce electrical energy from CGI with the highly efficient TE, the Stirling engine installed in a community trash is combined with a pump in circulating the water cooling. According to Piggott and Allen [5], there are several works on the cooling techniques used to increase different temperatures on the hot and cold sides. The power generated by the TE system is almost directly proportional to the temperature difference between the hot and the cold sides.

Ekpu et al., [6] proposed a pulsed cooling technology by cooling the devices in the short term on the hot spot using a pulse continually repeated for cooling in the long term. From their study and analysis with the SPICE program, they found that not only is there a steady increase in the coefficient of cooling performance but also the specific range, where there was a reduction in the cooling performance of the running pulse in the cooling rate with a continuous pulse in the long term. Thus, this is an in-depth analysis of the specific problems. Gurevich et al., [7] opined that to improve the cooling efficiency in microelectronic systems, the removal of excess heat using heat sinks is necessary. Gurevich et al., examined the effects of the changing shape of the heat sink made of aluminum and copper, affecting thermal performance in small electric devices. Thermal conductivity of heat sink materials is temperature dependent. Numerical studies on the thermal conductivity through the heat sinks, chip, and temperature of the surface material are of different thickness and height of heat sink, including the minimum and maximum temperature of the aluminum-and-copper heat sink. Both models were verified by analysis of the thermal conductivity at a steady state. The thickness of the base and the height of fins and increasing aluminum and copper heat sink made heat dissipation better. The limiting factors of thermoelectricity also have an impact on the application. In addition, Gurevich et al., improved the efficiency of TE with vapor in the combustion chamber (TVC), using vapor aluminum to evaluate the advantages included in the high thermal conductivity, lightweight, and wide range. The configuration of the effective thermal conductivity of the aluminum vapor chamber with TE module trials and computer simulation showed that the thermal conductivity of vapor of aluminum is better than isotropic. There is a thermal conductivity of 8363 Wm^{-1} K^{-1} of TE, and TVC systems enhanced their ability significantly at the same conditions.

This work presents the cooling technique for the TE module through the Stirling engine, where the water pump for cooling made the different temperature on both hot and cold sides. The experimental result of the cooling heat sink system was further compared with the Stirling engine system for future research of the CGI-TEG.

Materials and Methods



(a) (b)

Fig. 1 The structure of (a) the semiconductor of the TE and (b) the equivalent circuit [2].

Energy Conversion of TE

A thermocouple was made from a semiconductor p-type and n-type in the TE device. There are two legs and a joint constructed with a metal conductor as shown in Fig. 1 (a), where the p and n materials are p-type and n-type TE materials, respectively. The Seebeck coefficient (S) of a p-type (S_p) is a positive value, while, an n-type (S_n) is a negative value. Therefore, the S is $S_{pn} = S_p - S_n$. Figure 1 (a) shows that the TE module is made of two different materials which had different temperatures between two joints, the cold junction (T_{CJ}) and hot junction (T_{HJ}). Suppose open circuit loop at cold junction gets the voltage and open circuit (V_G), $V_G = \Delta V_{pn}$ is voltage between the conductor p and n in Seebeck effect, then V_G is the ratio of the temperature difference as given in equation (1):

$$V_G = \Delta V_{pn} = S_{pn}(T_{HJ} - T_{CJ}) \tag{1}$$

where $S_{pn} = S_p - S_n$ is S between p and n. To clearly explain the nature of the problem, Fig. 1 (b) shows the junction which has a low level of heat connecting to electrical resistance. Moreover, the heat and radiation should be used for analysis. So, defining S as the Seebeck coefficient, ρ as an electrical resistance, and κ as the thermal conductivity of non-temperature materials, after valuing load resistance (R_L) to TE is endangered in the flow of electricity (I_L) as shown in equation (2):

$$I_L = \frac{V_G}{R_{in} + R_L} = \frac{S_{pn}(T_{HJ} - T_{CJ})}{R_{in} + R_L} \tag{2}$$

where R_{in} is an internal resistance between two legs as shown in equation (3):

$$R_{in} = \frac{2\rho h}{A_{leg}} \tag{3}$$

where h and A_{leg} represent the length and cross-section area of the thermocouple legs, respectively. The exchange of heat and cold at the junction is called heat rate, which is the total of the Peltier reaction from Fourier’s rule, where the heat conduction flows through the two legs of the TE materials and the heat loss due to their electric flow. After considering the heat that flows in and out from the TE device by defining Q_H as the heat loss from the source to the junction of the cold around the area to the ceramic plate. The Q_C and Q_H could be explained by equations (4), (5) and (6) given as:

$$Q_H = S_{pn} T_{HJ} I_L + K_{in}(T_{HJ} - T_{CJ}) - 0.5 I_L^2 R_{in} \tag{4}$$

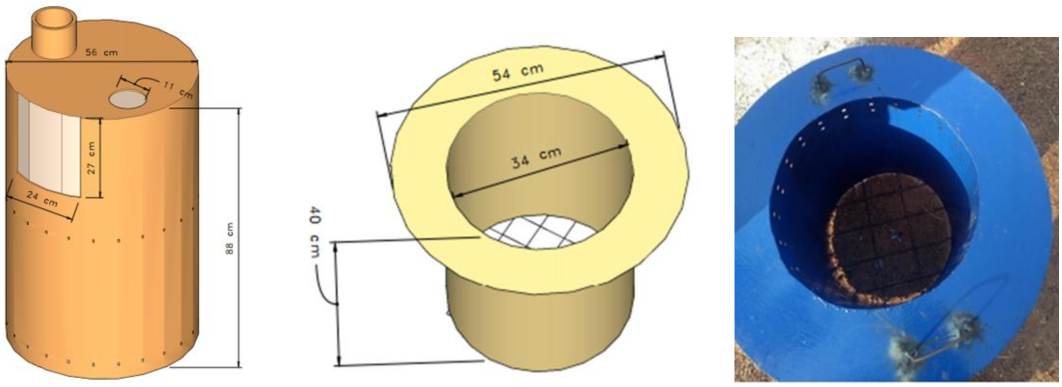
$$Q_C = S_{pn} T_{CJ} I_L + K_{in}(T_{HJ} - T_{CJ}) - 0.5 I_L^2 R_{in} \tag{5}$$

The internal heat conduction between the two TE legs is given as:

$$K_{in} = \frac{2\kappa A_{leg}}{h} a \tag{6}$$

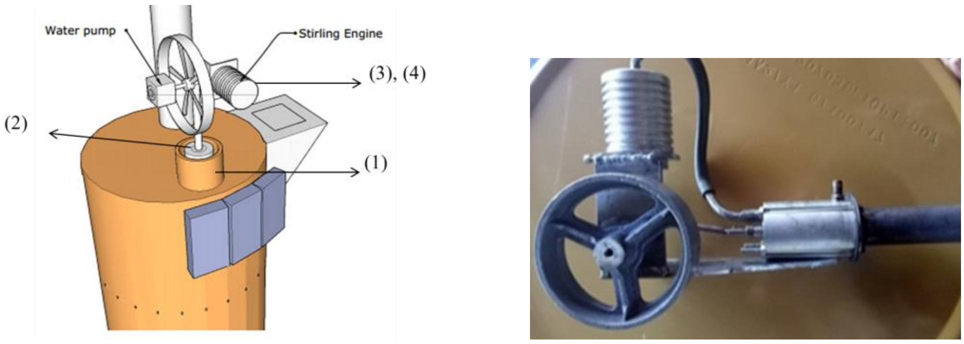
Design and Experimental Set-Up

Figure 2 (a) shows that the external structure of the incinerator, and the top cover is a circle of size 11 cm for air-vent-pipe. The area coverage of the tank measures 24 × 27 cm^2 for filling the trash. The front section cuts in a curve to under the trash with size 20 × 45 cm^2. The drilling hole in the middle and under edge size is 1 cm, and ten holes were made. Figure 2 (b) shows the trash strainer, with height 40 cm, the internal incinerator made from a half division of the two-hundred-liter tank and cut cover side to reduce the diameter of the tank to 34 cm, and the top cover used for the edge of the internal incinerator, 54 cm wide with an hole drilled on the top, where each hold size is 0.80 mm drilled by two holes per line including twenty-four lines. Figure 2 (c) shows the designed strainer was used as the internal device in the incinerator.



(a) (b) (c)

Fig. 2 The incinerator including (a) the external structure, (b) trash strainer, and (c) the strainer.



(a) (b)

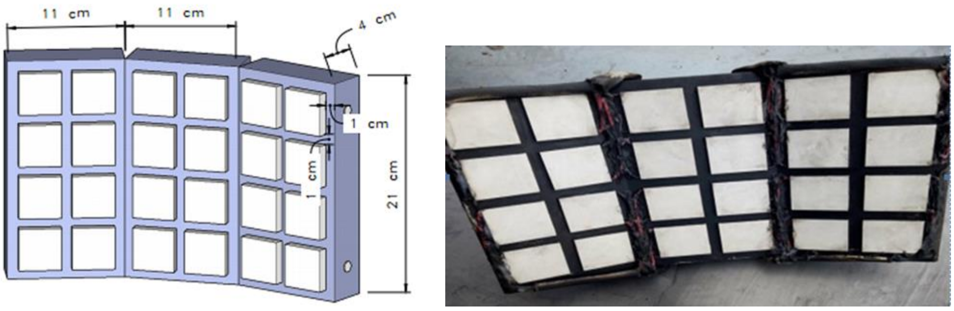
Fig. 3 The small Stirling engine including (a) the design and (b) the Stirling.

Figure 3 (a) shows that the Stirling engine is composed of; (1) the below hot cylinder, (2) the top hot cylinder, (3) the cold cylinder, and (4) the piston with different sizes 4 × 12 cm^2, 6 × 8.50 cm^2, 6 × 9 cm^2, and 3.50 × 4 cm^2, respectively. Figure 3 (b) shows the small Stirling engine from the design for water cooling of the pump. The Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gases at different temperatures, such that there is a net conversion of the heat energy to mechanical work. Specifically, the Stirling engine is a closed-cycle regenerative heat engine with a permanently gaseous working fluid. The closed cycle, in this context, means a thermodynamic system, where the working fluid is permanently contained within the system, and the regenerative describes the use of a specific type of internal heat exchanger and thermal store, also known as the regenerator. In a nutshell, the inclusion of the regenerator differentiates the Stirling engine from other closed cycles [9].

Figure 4 (a) shows the design is composed of 2 parts: (1) the position of the thermoelectric connected with the cooling box. There are three sets of TE; each set composes of 8 modules. The total is 24 modules connected by a series circuit. Each clearance is 1 cm. (2) module size is 4 × 40 × 3.40 cm^3 and had 1 cm hole in runoff water, while Fig. 4 (b) shows the small Stirling engine from the design. The inside is a V_G circuit with generator number; SP1848-27145 and size 40 × 40 × 3.40 mm^3. From Fig. 5 (a) shows that the prototype for municipal CGI produces electricity with TE height 180 cm. There is a cavity filled trash bucket outpost on the edge. The hole in the middle and the bottom of the tank aids oxygen increase in the combustion chamber. Figure 5 (b) shows that the secondary channel is positioned below the ashes.

The TE position is the height from below the tank 62 cm, while TE distance from the tank is 2 cm. The reason is to install the TE set on the top of the cylinder rim. The hole in the center of the tank is a two-story furnace, which, when burned, will spread the heat to the top. The hole in the center of the tank is a two-story furnace, which, when burned, will spread the heat to the top. Figure 5 (c) shows that the heat radiates out the better side.

Leaves or dry twigs used as garbage is in the amount of 6 kg per test and were brought to the incinerator in every 5 min. There is a Stirling engine to cool down the TE. Data is collected every 5 min after the combustion begins until completed. Figure 6 shows the average time is 30 min per test.



(a) (b)

Fig. 4 (a) The designed TE set and (b) the constructed TE set.

(a) (b) (c)

Fig. 5 Incinerator (a) CGI prototype (b) Stirling engine is the water pump which cooling down a Module TE and (c) Positioning and installation of the TE set which setting up in the incinerator.

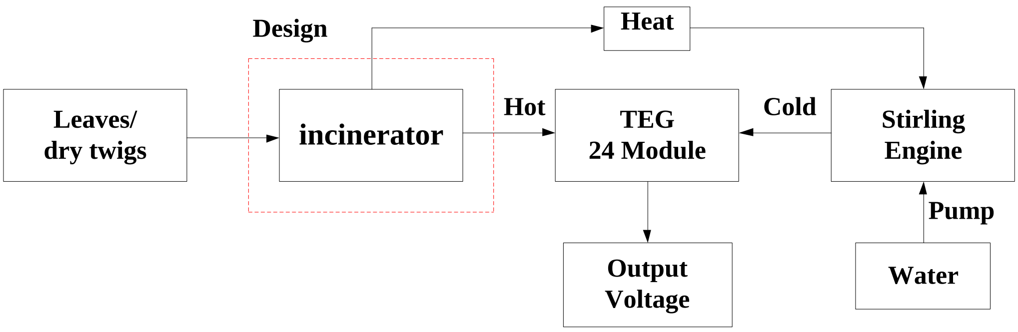


Fig. 6 Block diagram of the experimental set-up.

Results and Discussion

Incineration is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration of waste materials converts the waste into ash, flue gas and heat. Electricity can be generated by burning solid waste found in the landfills. A community must have a waste to energy facility that incinerates garbage and transforms chemical energy into thermal energy and the most common technology for waste to energy conversion is incineration. Some leaves and dry twigs for burn testing as dry garbage were put in the community incinerator for electricity generation. Six (6 kg) of garbage were used in each experiment with 1 kg each filled every 5 min using a Stirling engine to cool down the TE. To collect the data every 5 min, it took 30 min for one cycle testing. The process was repeated and the data collected ten times.

Figure 7 shows the average V_{out} of the TE set, which does not connect to an open circuit at the first 5 min. The result is 15.46 V for a minimum V_{out} and because of the duration, the efficiency of the combustion is not complete, and there is a strong wind. The heat in the incinerator is not hot enough, so the expansion of heat was impacted to the hottest of TE. To make the TE generated V_{out} efficient it does not reach the limit. The V_{out} of the TE set is 20.71 V. This is an average V_{out} and the highest in 10 min of incineration. Figure 8 shows there is a relationship between TE temperature and V_{out}. We observed that the average of temperature is 67.70 °C and the average of V_{out} is 20.71 V. It shows the temperature and V_{out} that came from the TE set confirmed the theory of equation (1). Figure 9 shows the average temperature is a difference between hot and cold TE temperatures.

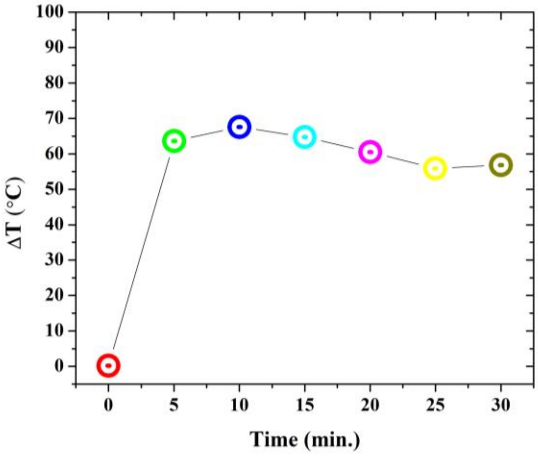


Fig. 7 The average different temperature of TE set.

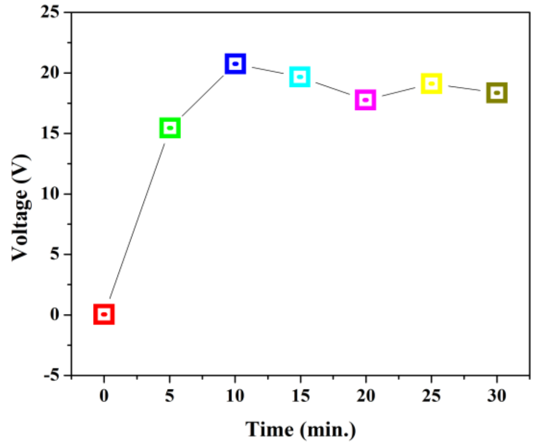


Fig. 8 The relation between TE time and V_{out}.

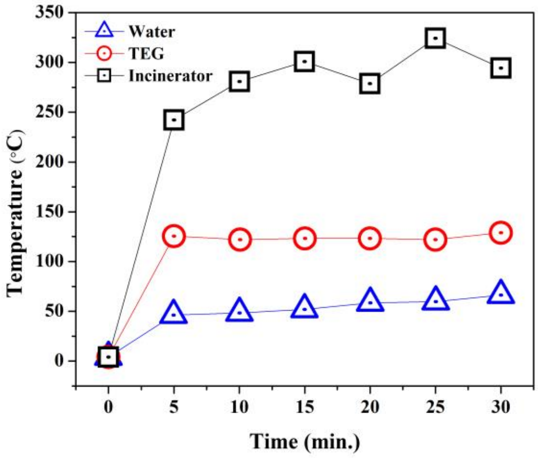


Fig. 9 The temperature at areas of community garbage incinerator.

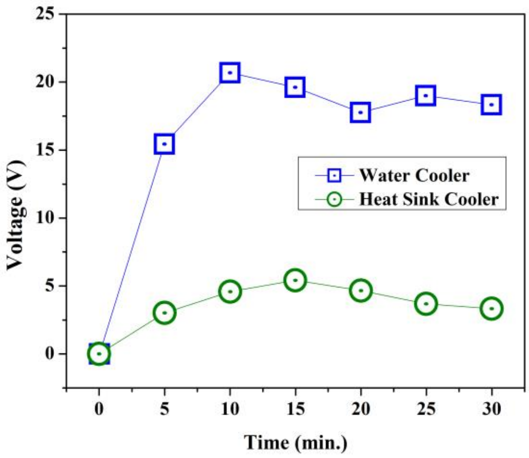


Fig. 10 The comparison of V_{out} between water cooling and heat sink.

Table 1 Comparison temperature at areas of community incinerator.

Type of incinerator	Average temperature at areas of the incinerator (°C)			
	Incinerator	**TEG contact**	**Water**	**Heat sink**
Designed incinerator/ water cooling	335.63	107.25	51.35	-
Ordinary incinerator / cooling by heat sink	238.00	81.80	-	60.30

Figure 9 shows the two parts of the community incinerator temperature has an average of 287.97 °C. We used Infrared Thermometer device GM550 in the range of -50 – 550 °C to take the temperature of the incinerator and designed the incinerator to be 2 shelves as shown in Fig. 2 and Fig. 5. We punched the incinerator around to increase the quantity of oxygen inside the incinerator in order to complete the incineration procedure. All of this made us get a high temperature of CGI. Also, part two is a difference in temperature between the hot and cold sides of the TE sheet. The average temperature of the hot side is 100.96 °C, while the cold side is 37.42 °C. Hence, the average difference in temperature between the hot and cold side is 67.70 °C, which relates to the qualification of the TEG Module sheet [10]. Figure 10 and table 1 shows the different comparison of both V_{out} from the TE and temperature around the incinerator areas. The designed incinerator is perfect than an ordinary incinerator, and affects the V_{out}. We acquired because we brought the technique of liquid cooling, which has a difference between the hot and cold side that is more proper than the ordinary incinerator.

Conclusion

This research presents the efficiency increment technique of V_{out} generated with liquid cooling on the cold side of the TE set using the stirring engine to pump water continuously. As for the hot contact from the incinerator, the set of the TE was designed to be 2 cm away from the incinerator to prevent the dilapidation of the TE set because it will extremely receive heat from the incinerator. The community incinerator was designed to have two shelves for increasing the efficiency. After that, we compared the V_{out} with the incinerator cooling by heat sink. The result showed that the designed community incinerator, which is water cooling, has perfect combustion rate from the average of incinerator temperature and V_{out}. There is a better average because there is a difference of temperature between hot and cold side that is more proper. Also, it has more V_{out} generated to 23.94%.

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