EPI International Journal of Engineering
Volume 1, Number 2, August 2018, pp. 51-58
DOI: 10.25042/epi-ije.082018.08

*p*ISSN 2615-5109
*e*ISSN 2621-0541

Heat Utilization of Incinerator Chimneys as Mini Power Generator Based on Thermoelectric

Usman Syamsuddin[a], Zulkifli Djafar[b], Thomas Tjandinegara[c], Zuryati Djafar[d], Wahyu Hariyadi Piarah[e]

[a]Department of Mechanical Engineering, Hasanuddin University. Email:usmansyamsuddin69@gmail.com
[b]Department of Mechanical Engineering, Hasanuddin University. Email:zulkiflidjafar@unhas.ac.id
[c]Department of Mechanical Engineering, Hasanuddin University. Email:thomastjandinegara@unhas.ac.id
[d]Department of Mechanical Engineering, Hasanuddin University. Email:zuryatidjafar@unhas.ac.id
[e]Department of Mechanical Engineering, Hasanuddin University. Email:wahyupiarah@unhas.ac.id

Abstract

The thermoelectric generator (TEG) has long been used to produce electrical energy. When a temperature difference occurs between two semi-conductor materials on TEG, this thermoelectric element will produce a voltage difference and flow an electric current known as the 'Seebeck effect'. This research was conducted to determine the potential of electrical energy from the TEG module as an alternative energy source by utilizing chimney heat from an incinerator for household non-organic waste. Tests are carried out with a variation of 1, 2 and 3 m chimney height with solid waste treatment without compaction and compaction. The test results show that with 12 TEG modules arranged in series electricity can produce an output voltage with a maximum temperature difference of each ΔV 3.31 Volt ; ΔT 15.0 °C (1 m), ΔV 3.92 Volt; ΔT 17.8 °C (2 m), ΔV 4.84 Volt ; ΔT 22.0 °C (3 m) while the compaction of each value ΔV 6.34 Volt ; ΔT 29.2 °C (1 m), ΔV 7.69 Volt ; ΔT 35.2 °C (2 m), ΔV 9.09 Volt ; ΔT 41.5 °C (3 m). The potential power that can be produced is as big as 3.22 W (1 m); 4.56 W (2 m); 6.88 W (3 m) while the compaction of waste is equal to each value 11.80 W (1 m); 17.36 W (2 m); 24.25 W (3 m). The addition of chimney height variation resulted in an increase in the hot side temperature (Th), cold side (Tc) and temperature difference (ΔT) so that heat energy and power energy increased.

Keywords: Electrical energy; heat transfer; incinerator; seebeck effect; thermoelectric generator

1. Introduction

Energy cannot be separated from human life in carrying out their daily activities. The need for energy is increasing along with the development of technology. However, not all energy sources used can be renewed so that one day the energy source will run out, such as fossil energy. Fossil energy is energy derived from fossil resources such as coal and petroleum that occur due to fossil stockpiling for millions of years. Fossil energy sources can run out at any time if it is used continuously and ironically, fossil energy is the most widely used [1].

Development of alternative energy such as wind energy, solar cell, OTEC (Ocean Thermal Energy Conversion), geothermal energy, river flow, waste and other sources of plant origin such as jatropha and biogas energy need attention the serious ones from government, industry, universities and society. In addition to the development of alternative energy, attention to saving energy or conserving energy needs to get the same attention because saving energy or increasing the thermal efficiency of an energy system can extend the depletion of fossil fuel supplies [2].

The thermoelectric generator (TEG) is a power plant based on the Seebeck effect, which was first discovered in 1821 by Thomas Johann Seebeck. The working principle of the Seebeck effects that works on a thermoelectric generator system are: if two metal materials (generally semi conductors) are connected in an environment with different temperatures, the material will flow electric current or electromotive force. If this effect is applied to an incinerator with a waste heat temperature that has an interval of 200-1500 °C, the temperature difference between the two can be used to obtain an electromotive force [3].

*Corresponding author. Tel.: +62 853-422-724-69
Faculty of Engineering Hasanuddin University
South Sulawesi, Indonesia, 90245

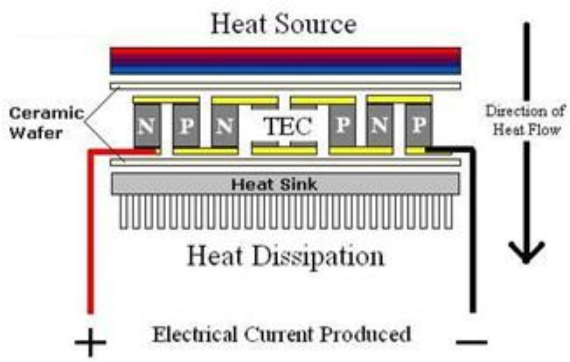

Figure 1. Thermoelectric power generation structure [4]

Figure 1 shows the structure of a Thermoelectric Generator (TEG) which consists of an array of n-type elements (material with an excess of electrons) and p-type (material with a lack of electrons). Heat to enter on one side and is discharged from the other side, producing a voltage that passes through the thermoelectric connection. The amount of voltage produced is proportional to the temperature gradient.

In a that developed a thermoelectric based battery charger. The system developed produces a maximum power of 7.99 Watts. The study uses heat source of heat dissipation from the walls of traditional furnaces. This thermoelectric generator has also been developed for application of laptops. The plant uses heat generated from butane gas. The power produced is around 13.35 Watt [4]. Another study that developed and tested a thermoelectric plant in a traditional fire furnace in Lebanon using free convection on the thermoelectric side which produced a power of 4.2 Watt [5].

There are several advantages of using a thermoelectric generator (TEG) as a means of converting heat of electricity, including safe for the environment, simple, small, very light, noiseless and does not require maintenance because there are no moving parts. Besides its advantages, low efficiency is still a major drawback of TEG. However, because the energy source to activate this technology is obtained from free heat sources available, the low efficiency problem is not the main barrier factor of its application. In addition, several steps to increase efficiency can be obtained by optimizing its components, improving manufacturing quality and better design and the development of materials used [6].

The efficiency value of the thermoelectric module can be increased by the way the heat is dissipated on the cold side of the module, such as the use of heatsink, fan, water jacket or simply by giving the ambient temperature above the cold side of the module to maintain the temperature difference in the heat side. Use of heat sinks to help increase heat release on the cold side, thereby increasing the efficiency of the module. The power generation potential for a single thermoelectric module will vary depending on size, construction and temperature differences. The greater temperature difference between the hot side and the cold side of the module will produce greater voltage and current. Thermoelectric modules can also be connected together in series or parallel like a battery to produce the desired voltage or electric current. Each module is able to produce an average voltage of 1-2 V DC and even up to 5 V DC depending on variations in temperature difference, but generally one thermoelectric module produces 1.5-2 V DC [7].

2. Experimental Methods

The design of the equipment used is presented in Figure 2 below. A holder made of thin rectangular aluminum plates as a place to place the TEG module and mounted on an incinerator chimney that functions to use heat to generate electricity, in this case voltage difference. In this test, a single module is used with 3 variations on chimney height 1, 2 and 3 meters. A single module uses 12 TEGs that is spread in a series with an electric series circuit (Fig. 3). The cool heatsink and fan are installed above the TEG module which serves to remove heat of the cold side so that the temperature difference can be maximized.

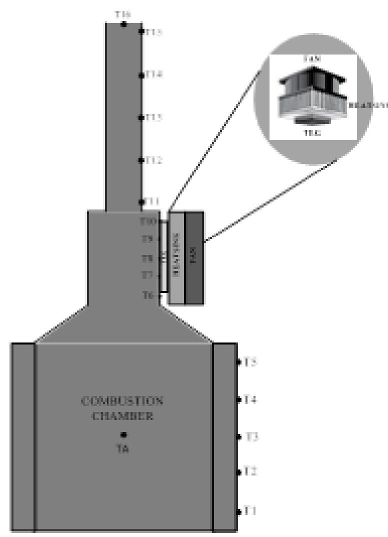

Figure 2. Test equipment design

Information:

- Fire temperature measurement point (TA)
- Lower body temperature measurement point (T1 to T5)
- Upper body temperature measurement point (T6 to T10)
- Chimney temperature measurement point (T11 to T15)
- Exhaust gas temperature measurement point (T16)

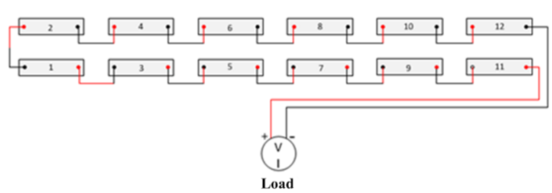

Figure 3. Single series electric module circuit (12 TEG)

The output voltage of the TEG module is measured using a multimeter after a while getting heat flow from the aluminum plate. Measurement of hot side temperature (Th), cold side (Tc) and voltage (ΔV) of the TEG module is carried out with an interval of 3 minutes for 60 minutes. The data obtained is then recorded in the observation table.

In analyzing the performance of the thermoelectric module, the Seebeck coefficient that describes the voltage (electromotive force) arises because the temperature difference becomes very important. The Seebeck coefficient can be expressed by the following equation [8, 9]:

$$\alpha = \frac{\Delta V}{\left(T_h - T_c\right)} \quad (1)$$

Where:

ΔV = Voltage difference (V)

α = Seebeck coefficient between two semiconductor materials, P and N (V/°C)

T_h = Temperature of the thermocouples on hot side (°C)

T_c = Temperature of the thermocouples on hot side (°C)

While the generated electric current is given by the following equation [10]:

$$I = \frac{\alpha\ \Delta T}{R_i + R_L} = \frac{\alpha\ \Delta T}{R_i + R_L} \quad (2)$$

Where:

I = Electric current flowing in the circuit (A)

R_i = Internal load of the thermoelectric generator module (Ω)

R_L = External load (Ω)

ΔT = Th – Tc (°C)

The rate of heat transfer (Q_h) coming from the heat source of temperature (T_h) to the cold surface at a temperature (T_c) is as follows [6]:

$$Q_h = \left(\alpha\ I\ T_h\right) + K\left(T_h - T_c\right) \quad (3)$$

where K is the thermal conductance of the module element (W/M °C). The output power (P) which generated to counter the outside loads [6] and the efficiency (η) of thermoelectric generator is as follows [8]

$$P = I^2 R_L \quad (4)$$

$$\eta = \frac{P}{Q_h} \quad (5)$$

3. Result and Discussion

3.1. *Without compaction waste of 1 m chimney*

Figure 4 shows the history of average hot side temperature (Th *avg*), average cold sides temperature (Tc *avg*) and average temperature difference (dT *avg*) to the time, t (minute) which increases over time and reaches the peak in the 9th minute. Furthermore, it decreased continuously until it approached the ambient temperature in the 60th minute. The biggest value of each is; Th avg is 76.0 °C, Tc *avg* is 61.0 °C and dT *avg* is 15.0 °C. The picture above shows that the temperature has increased from the combustion processed until the peak conditions where the burning waste has reached the maximum amount. Furthermore, the temperature decreases continuously until the garbage burn out.

Figure 5 shows the relationship between voltage difference (dV) and temperature difference (dT). The temperature range that can be achieved is 15.0 °C which corresponds to the voltage difference is 3.31 V. This shows that the Seebeck coefficient value of this process is still relatively small at 0.22 V/°C because the TEG module used is of low quality (home industrial production).

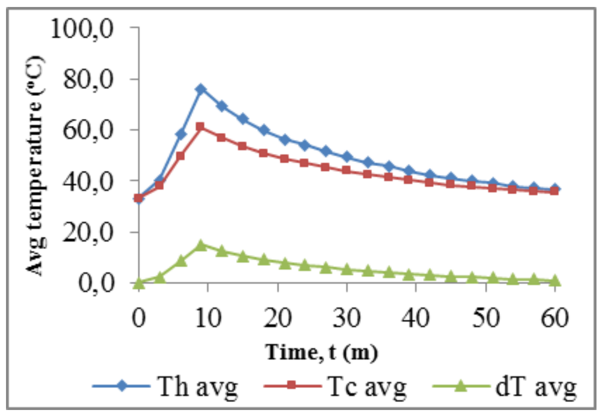

Figure 4. History of average hot side temperature (Th avg), average cold side temperature (Tc avg) and average temperature difference (dT avg) at 1 m chimney height

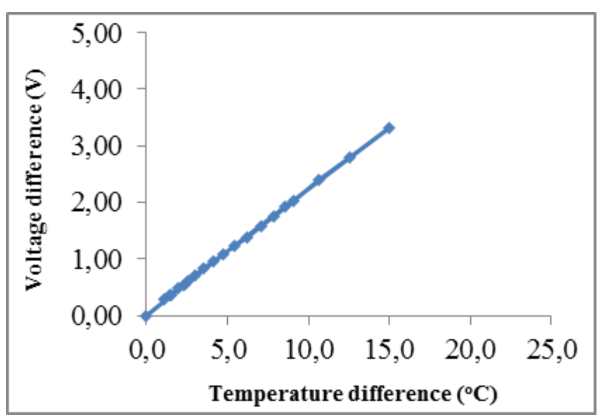

Figure 5. Relationship between voltage difference (dV) to temperature difference (dT) at 1 m chimney height

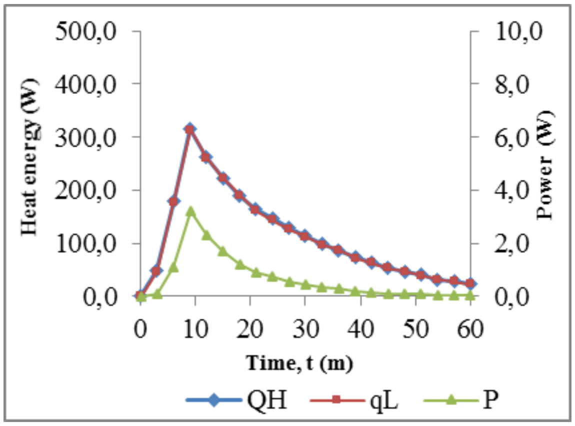

Figure 6. Comparison of power (P), heat energy absorbed (QH), heat loss energy (qL) to time, t (m) at 1 m chimney height

Figure 6 shows the ratio of power (P), absorbed heat energy (QH) and the heat loss energy (qL) to the time that increased until the 9th minute then decreased continuously until it approached the surrounding temperature in the 60th minute. absorbed by 315.60 W is converted to a power of 3.22 W and the rest is released into the surrounding environment. This result is for conditions without compaction of waste with a 1 m chimney height.

3.2. *Compaction waste of 1 m chimney*

Figure 7 shows the history of average hot side temperature (Th avg), average cold sides temperature (Tc avg) and average temperature difference (dT avg) to time, t (m) which increased with time and peaked at 6th, then it decreased continuously until it approached the surrounding temperature at 60th. The biggest value of each was; Th avg is 113.4 °C, Tc avg is 84.4 °C and dT avg is 29.0 °C. The temperature experienced a significant increase when compared to conditions without compaction of waste because the conditions of compaction of the waste combustion process is faster so that the temperature also increases on the hot side, on the cold side and temperature difference.

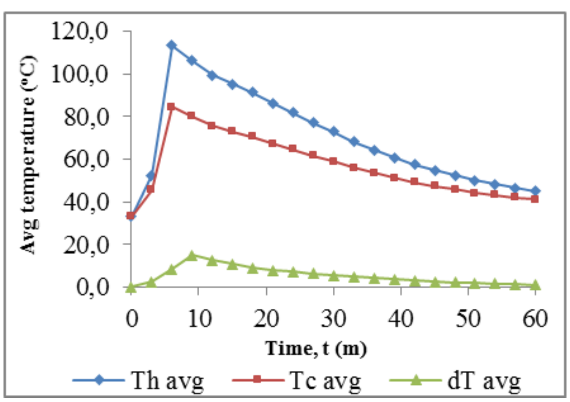

Figure 7. History of average hot side temperature (Th avg), average cold side temperature (Tc avg) and average temperature difference (dT avg) at 1 m chimney height

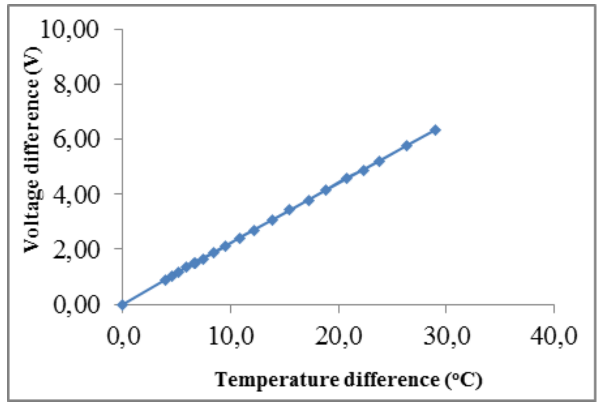

Figure 8. Relationship between voltage difference (dV) to temperature difference (dT) at 1 m chimney height

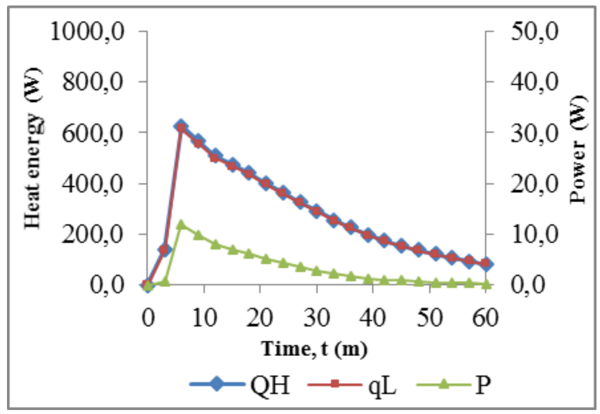

Figure 9. Comparison of power (P), heat energy absorbed (QH), heat loss energy (qL) to time, t (m) at 1 m chimney height

Figure 8 shows the relationship between voltage difference (dV) and temperature difference (dT). The temperature difference that can be achieved is 29.0 °C which corresponds to the voltage difference is 6.34 V. Seebeck coefficient in this process of 0.18 V/°C as in the previous case.

Figure 9 shows the comparison of power (P), absorbed heat energy (QH) and the heat loss energy (qL) against the time that increased until the 6th minute then decreased continuously until it approached the surrounding temperature in the 60th minute. absorbed by 625.11 W is converted into power of 11.80 W and the rest is released into the surrounding environment. This result is for compaction conditions with 1 m chimney height.

3.3. *Without Compaction waste of 2 m chimney*

Figure 10 shows the history of average hot side temperature (Th avg), average cold sides temperature (Tc avg) and average temperature difference (dT avg) to time, t (m) which increased with time and peaked at 9th, then it decreased continuously until it approached the surrounding temperature at 60th. The biggest value of each was; Th avg of 83.6 °C, Tc avg of 65.7 °C and dT avg of 17.9 °C. The temperature experienced a significant increase when compared to conditions without compaction of waste because the condition of compaction of the waste combustion process is faster so the temperature also increases on the hot side, cold side and temperature difference. The addition of 2 m chimney height variations also has a significant effect due to the increase in cross-sectional area so that it affects the increase in temperature.

Figure 11 shows the relationship between voltage difference (dV) and temperature difference (dT). The temperature difference that can be achieved is 17.9 °C which corresponds to the voltage difference is 3.94 V. Seebeck coefficient in this process of 0.22 V/°C

Figure 12 shows the comparison of power (P), absorbed heat energy (QH) and the heat loss energy (qL) against the time that increased until the 9th minute then decreased continuously until it approached the surrounding temperature in the 60th minute. absorbed by 378.14 W is converted to a power of 4.56 W and the rest is released to the surrounding environment. This result is for conditions without compaction of waste with 2 m chimney height.

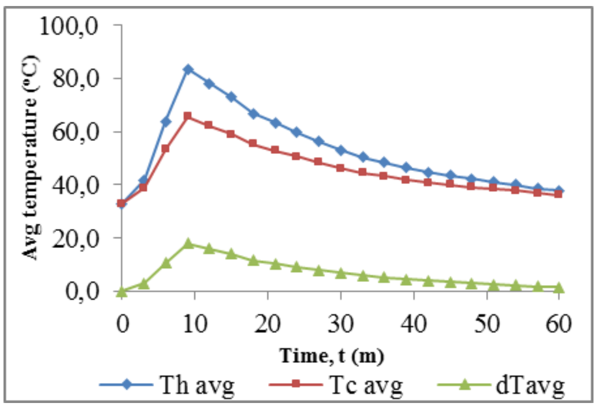

Figure 10. History of average hot side temperature (Th avg), average cold side temperature (Tc avg) and average temperature difference (dT avg) at 2 m chimney height

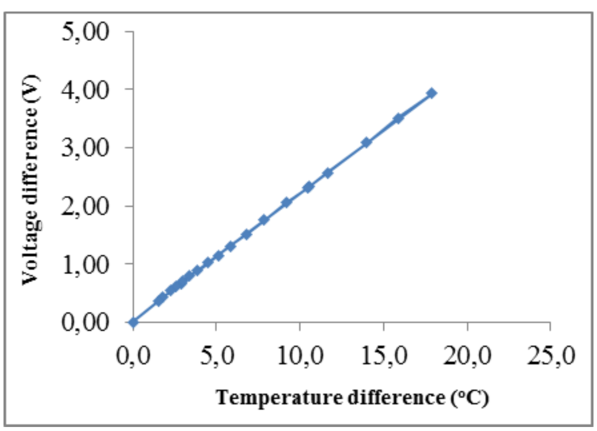

Figure 11. Relationship between voltage difference (dV) to temperature difference (dT) at 2 m chimney height

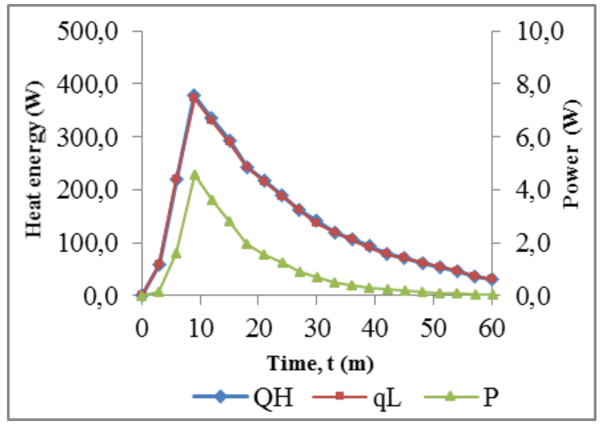

Figure 12. Comparison of power (P), heat energy absorbed (QH), heat loss energy (qL) to time, t (m) at 2 m chimney height

3.4. Compaction waste of 2 m chimney

Figure 13 shows the history of average hot side temperature (Th avg), average cold sides temperature (Tc avg) and average temperature difference (dT avg) to time, t (m) which increased with time and peaked at 6th, then it decreased continuously until it approached the surrounding temperature at 60th. The biggest value of each was; Th avg is 129.8 °C, Tc avg is 94.6 °C and dT avg is 35.2 °C. The addition of 2 m chimney height variations resulted in an increase in the voltage difference resulting from the increase in temperature difference due to the increase in chimney crosses section area.

Figure 14 shows the relationship between voltage difference (dV) and temperature difference (dT). The temperature difference that can be achieved is 35.2 °C which corresponds to the voltage difference is 7.69 V. Seebeck coefficient in this process of 0.22 V/°C.

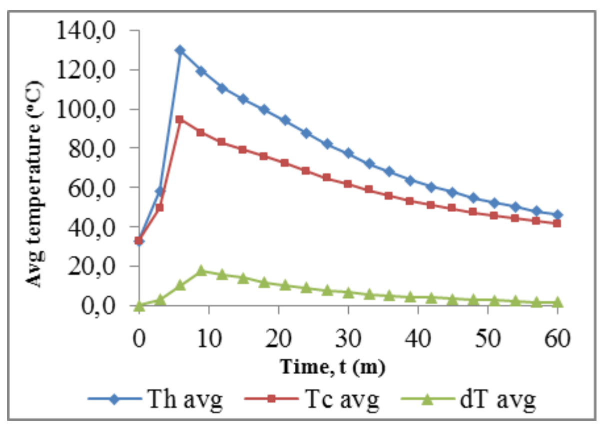

Figure 13. History of average hot side temperature (Th avg), average cold side temperature (Tc avg) and average temperature difference (dT avg) at 2 m chimney height

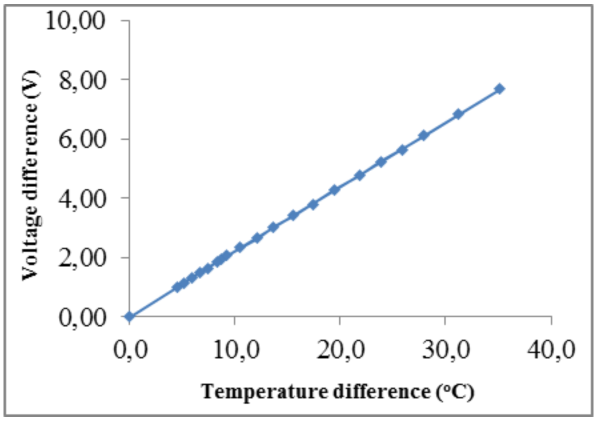

Figure 14. Relationship between voltage difference (dV) to temperature difference (dT) at 2 m chimney height

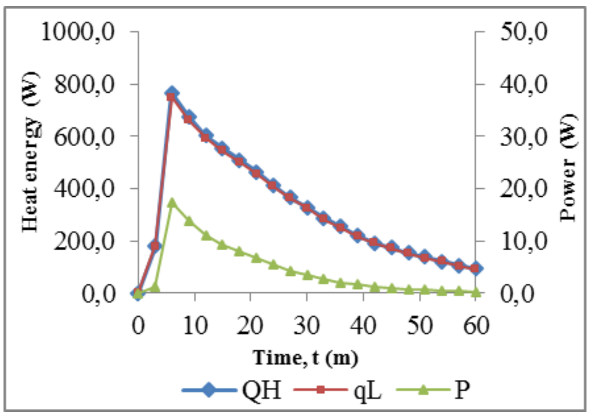

Figure 15. Comparison of power (P), heat energy absorbed (QH), heat loss energy (qL) to time, t (m) at 2 m chimney height

Figure 15 shows the comparison of power (P), absorbed heat energy (QH) and the heat loss energy (qL) to the time that increased until the 6th minute then decreased continuously until it approached the surrounding temperature in the 60th minute. absorbed by 765.45 W is converted to a power of 17.36 W and the rest is released into the surrounding environment. This result is for conditions without compaction of waste with 2 m chimney height.

3.5. *Without Compaction waste of 3 m chimney*

Figure 16 shows the history of average hot side temperature (Th avg), average cold sides temperature (Tc avg) and average temperature difference (dT avg) to time, t (m) which increased with time and peaked at 9th, then it decreased continuously until it approached the surrounding temperature at 60th. The biggest value of each was; Th avg is 94.7 °C, Tc avg is 72.7 °C dan dT avg is 22.0 °C. The addition of 3 m chimney height variations resulted in an increase in the voltage difference resulting from the increase in temperature difference due to the increase in chimney crosses section area.

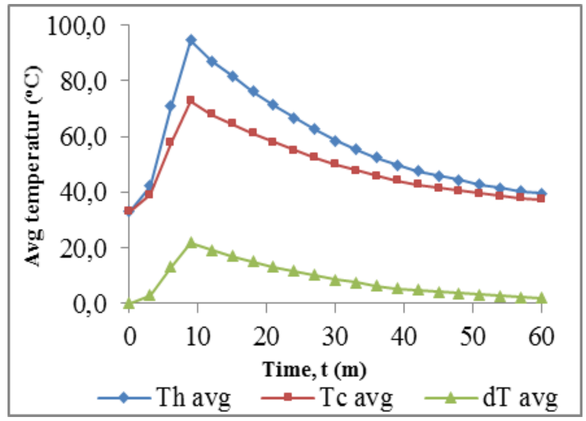

Figure 16. History of average hot side temperature (Th avg), average cold side temperature (Tc avg) and average temperature difference (dT avg) at 3 m chimney height

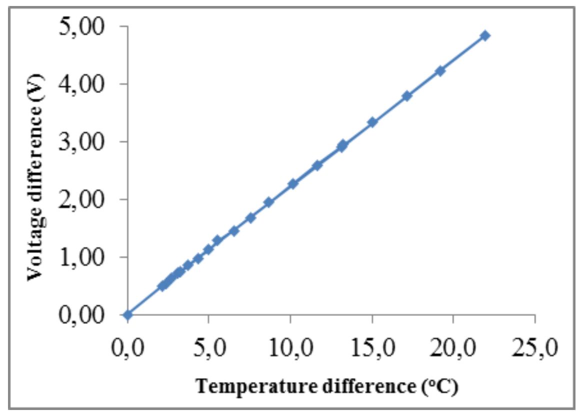

Figure 17. Relationship between voltage difference (dV) to temperature difference (dT) at 3 m chimney height

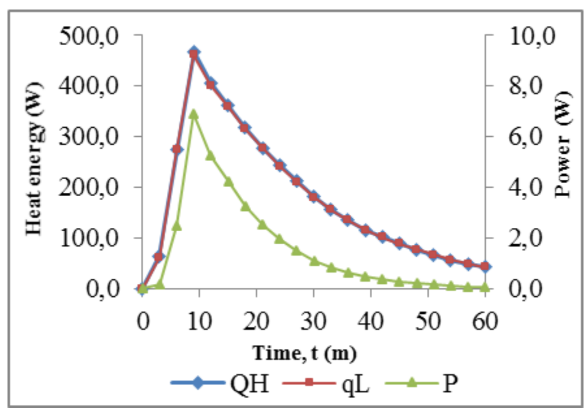

Figure 18. Comparison of power (P), heat energy absorbed (QH), heat loss energy (qL) to time, t (m) at 3 m chimney height

Figure 17 shows the relationship between voltage difference (dV) and temperature difference (dT). The temperature difference that can be achieved is 22.0 °C which corresponds to the voltage difference is 4.84 V. Seebeck coefficient in this process of 0.22 V/°C.

Figure 18 shows the comparison of power (P), absorbed heat energy (QH) and the heat loss energy (qL) to the time that increased until the 9th minute then decreased continuously until it approached the surrounding temperature in the 60th minute. absorbed by 467.95 W converted to a power of 6.88 W and the rest is released to the surrounding environment. This result is for conditions without garbage compaction with a 3 m chimney height.

3.6. *Compaction waste of 3 m chimney*

Figure 19 shows the history of average hot side temperature (Th avg), average cold sides temperature (Tc avg) and average temperature difference (dT avg) to time, t (m) which increased with time and peaked at 6th, then it decreased continuously until it approached the surrounding temperature at 60th. The biggest value of each was; Th avg is 146.5 °C, Tc avg is 105.0 °C and dT avg is 41.5 °C. The addition of 3 m chimney height variations resulted in an increase in voltage difference resulting from the increase in temperature difference due to the increase in the chimney crosses section area.

Figure 20 shows the relationship between voltage difference (dV) and temperature difference (dT). The temperature difference that can be achieved is 41.5 °C which corresponds to the voltage difference is 9.09 V. Seebeck coefficient in this process of 0.22 V/°C.

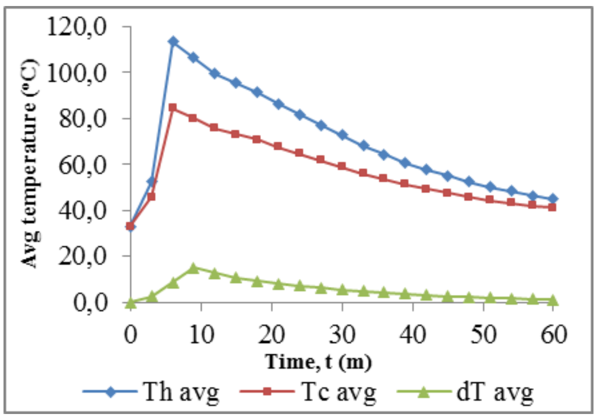

Figure 19. History of average hot side temperature (Th avg), average cold side temperature (Tc avg) and average temperature difference (dT avg) at 3 m chimney height.

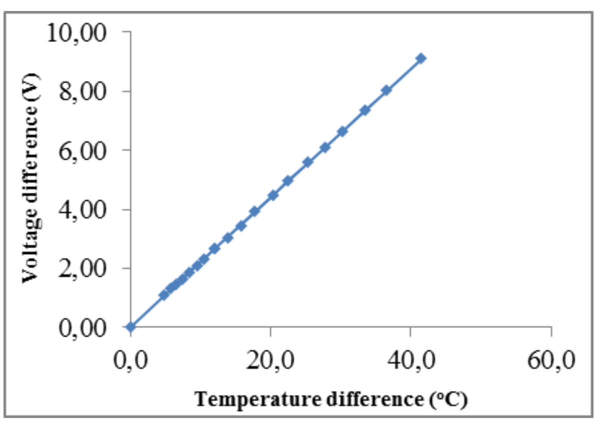

Figure 20. Relationship between voltage difference (dV) to temperature difference (dT) at 3 m chimney height

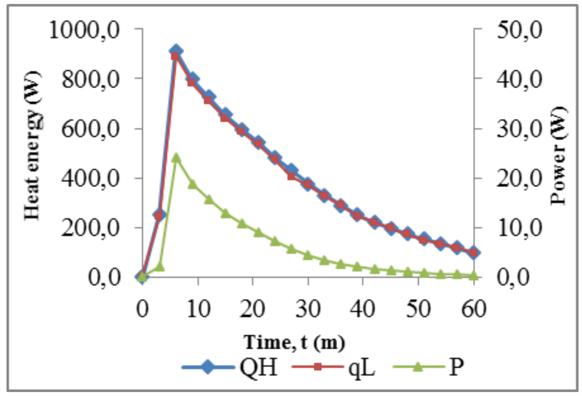

Figure 21. Comparison of power (P), heat energy absorbed (QH), heat loss energy (qL) to time, t (m) at 3 m chimney height

Figure 21 shows the ratio of power (P), absorbed heat energy (QH) and the heat energy released (qL) to the time that increased until the 6th minute then decreased continuously until it approached the surrounding temperature in the 60th minute. absorbed by 913.70 W is converted into power of 24.25 W and the rest is released into the surrounding environment. This result is for compaction conditions with 3 m chimney height.

4. Conclusion

The test results to indicate that the resulting voltage difference increases from the addition of chimney height with or without compaction of waste because it has not reached optimum height. The temperature difference also increases with each value of ΔV 3.31 Volt; ΔT 15.0 °C (1 m), ΔV 3.92 Volt; ΔT 17.8 °C (2 m), ΔV 4.84 Volt; ΔT 22.0 °C (3 m) while the compaction of each value ΔV 6.34 Volt; ΔT 29.2 °C (1 m), ΔV 7.69 Volt; ΔT 35.2 °C (2 m), ΔV 9.09 Volt; ΔT 41.5 °C (3 m). The potential power that can be produced is as big as 3.22 W (1 m), 4.56 W (2 m), 6.88 W (3 m) while the compaction of waste is equal to each value 11.80 W (1 m), 17.36 W (2 m), 24.25 W (3 m). The addition of chimney height variation resulted in an increase in the heat sides temperature (Th), cold side (Tc) and temperature difference (dT) so that heat and power energy increased.

References

[1] Kementerian Energi dan Sumber Daya Mineral, “National Energy management strategies in ensuring availability of Energy Security,” 2010.

[2] http://www.alpensteel.com/article/121-107--bio-gas-energy/2367--develovement-of-alternative-energy-from-biogas. Accessed on 07 February 2017.

[3] G. Min, D.M. Roe, Handbook of Thermoelectrics, Peltier devices as generator, CRC Press LLC, Florida, p. 479, 1994.

[4] J. Eakburanawat, I. Boonyaroonate, “Development of a thermoelectric battery-charger with microcontroller-based maximum power point tracking technique” J. Appl. Energy, 83/7, 687-704. 2006.

[5] Rida Y. Nuwayhid, Alan Shihadeh, Nesreen Ghaddar, “Development and Testing of a Domestic Woodstove Thermoelectric Generator with Natural Convection Cooling”, J. Energy Conversion and Management, Volume 46, Issues 9-10, 1631-1643.

[6] Nandy Putra, Raldi Artono Koetoer, M. Adhitrya, Ardian Roekettino, and Bayu Trianto., "The Potential Power Generation Thermoelectric for Hybrid Vehicles", J. Makara Teknologi. Vol. 13. No. 2., 53-58, 2009.

[7] Ismail, B.I., Ahmed, W.H., *Thermoelectric Power Generation Using Waste-Heat Energy as an Alternative Green Technology*, Recent Patents on Electricals Engineering, Vol. 2, p. 27-39, 2009.