Renewable Energy from Cooking Stove Waste Heat Energy using Thermoelectric Generator for Night Market Application

Mohd Arizam bin Abdul Wahap, Mohammad Haidir bin Maslan, Mohd Sharimienizam bin Harun, A Shamsul Rahimi bin Subki, Sharizal bin Saat

Abstract**:** ***Malaysia night market normally operated along a temporarily closed road. No electrical power provided by the authorities and therefore hawkers need to prepare their own. Currently, they are working with gasoline-electric generator. On top of the cost incurred, they also need to consume exhaust gas and noise from the machine. Further, this situation will also affect customers. With a high percentage of the hawkers involve with cooking activities using the LPG gas stove, excess heat is one of the potential energy which can be converted into electrical energy using a thermoelectric generator (TEG). The aim of this study is to convert the excess heat available used to powered night market electrical facilities. A set of experiments was conducted utilizing five units of TEG connected in series to convert excess heat from a butane gas stove to electrical power. The temperature at both the hot and cold sides of the TEG was recorded used to analyze the effect of power produced. Two electrical parameters namely voltage and current outputs were measured used to calculate the electrical power generated. The analysis focused on the two main governing parameters namely temperature different and Seebeck coefficient toward power generated. It was found that only some amount of excess heat was converted which produced up to 46.8 mW electrical power. This is based on the high temperature recorded at the cold side of the TEG. The almost constant trend showed in temperature different was contributed to a small magnitude of the Seebeck coefficient and so for the power generated. The trend showed by the power generated was also almost constant even the temperature on the hot side keep increasing. The energy conversion process was considered success and can be further increased by increasing the number of TEG units used as well as by incorporating a cooling mechanism as practiced by many researchers.***

Keywords**:** ***Night market, energy conversion, thermoelectric generator.***

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***** Correspondence Author

M.A. Abdul Wahap*, Faculty of Mechanical & Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia.

M.H Maslan, Faculty of Mechanical & Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia.

M.S. Harun, Faculty of Mechanical & Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia.

A.S.R. Subki, Faculty of Electrical & Electronics Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia.

S. Saat, Faculty of Electrical & Electronics Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia.

I. INTRODUCTION

The electrical energy source is one of the major concern for the night market hawkers in Malaysia. No electrical energy source provided by the authorities and thus, therefore, the majority of them are using a gasoline-fuelled generator [1,2] to powered fluorescent or LED light averaging between 50-100 W/hr [3]. This practice had increased its overhead cost as well as contribute to noise and air pollution [4]. Besides, these LED lights even can be powered using a dry cell battery [5]. Majority of the night market stalls are selling cooked food and beverage [6-9]. Hawkers normally using LPG type cooking stove at their stalls to prepare the food. This type of stove produces a huge amount of waste heat energy which is very high potential to be converted into electrical power which can be further used to power up the night market stall. This study interest is to convert the excess heat from the cooking activities at night market using TEG used to light up their stalls. The current trend which focusing on the renewable energy has given an opportunity to this study.

II. LITERATURE REVIEW

A. The scenario at Malaysia night market

Night market in Malaysia normally operates between 3.00 pm to 9.00 pm or event until midnight. Utilizing the temporarily closed roadside [6,10], this activity normally monopolized by the middle group people either the hawkers itself as well as the customer [11]. Since no electricity been provided, the hawkers have few alternatives such as gasoline generator, vehicle battery [2] and dry cell or power bank. The majority used to power lights with some other electrical appliances such as fan, radio, and speakers.

Range of product variety at night market is very wide as reported in [10] with a high percentage given by food and beverages (30% - 50%). Hawkers are using LPG gas tank with few different types of stoves depending on their food and size. For a large pan size which normally used to fry such as fried noodle, fried rice or even fried banana, a coverage made of aluminium was (Fig. 1) erected around the pan used to protect the customer from excess heat. This excess heat can be transferred through three mechanisms which are conduction, convection and radiation. In this research, the excess heat from hawkers cooking activity will be converted into electricity using TEG modules.

Fig. 1. Coverage setup (with texture) to reduce excess heat towards customer

B. Thermoelectric generator (TEG)

A thermoelectric generator (TEG) is a device that can straight forward convert heat energy into electrical energy without involving any moving parts [11]. Fig. 2 shows an overview of the module. TEG is a type of semiconductor where heat energy is used to propel the electron's movement between the two sides of hot and cold, hence produce current [12]. As for the operation, the hot side of the TEG will be attached on the heat source (hot side) while the other side (cold side) will leave to the atmosphere or attach to cooling mechanism [13]. The temperature difference between these two sides of the TEG ($\Delta T = T_{hot} - T_{cold}$) will determine the output of the conversion namely voltage, current and power. The relationship between temperature different and output voltage are as shows in equation (1). Seebeck coefficient is determined by the combination of the two materials used in constructing the TEG. This coefficient is not constant where it decreases over the increase in temperature difference [14]. Further, the power output (P_O) can be calculated based on equation (2).

$$V_O = \alpha_{TEG}(T_{hot} - T_{cold}) \quad (1)$$

$$P_{TEG} = V_O I_O \quad (2)$$

where

V_O = voltage generated by TEG
α_{TEG} = Seebeck coefficient
T_{hot} = temperature at the hot side of the TEG
T_{cold} = temperature at the cold side of the TEG
P_{TEG} = power generated by TEG
I_O = current generated by TEG

Various type of application in heat to electrical energy conversion involving TEG documented in [15,16]. These had cover from a various heat source such as solar, vehicle engines or components, air conditioning unit and even body heat [17]. In practice, a set of TEG will be installed together, either in series or in parallel to increase the output [18,19].

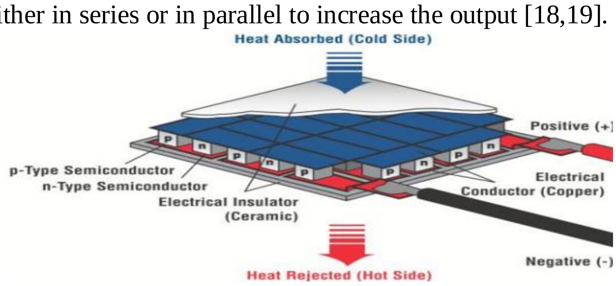

Fig. 2. Overview of the TEG module [20]

III. METHODOLOGY

Fig. 3 (a) and (b) show the schematic diagram and the top view of the experimental setup. This setup used five sets of TEG modelled SP1848-27145 which were connected in series. The modules were arranged next to each other to minimize the length of wiring and hence the potential current loss due to wiring. The terminals of the modules are then connected to a 2V rating LED. The hot side of the TEGs was pasted on a 0.5 mm thick copper plate using thermal paste. This copper plate was used to transfer the heat energy from a portable butane gas burner (heat source). It is important to collect heat form the highest possible heat source [16]. In this experiment, the copper plate was directly placed on top of the burner flames. Further. the cold side of the TEGs just leaves to the room temperature without any cooling mechanism. The measured room temperatures throughout the experimental process were between 23.6 °C to 25.2 °C.

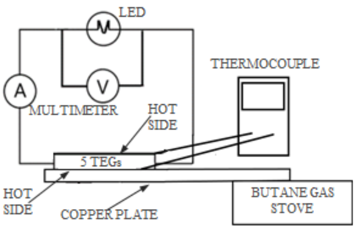

Fig. 3(a). TEG's schematic design Fig. 3(b). Top view of TEG setup

Two units of digital multimeter were used to measure the output voltage and current. The multimeter was arranged in series with the load to measure the current, and in parallel to measure the potential difference across the load (refer Fig. 3(a). Later, the temperature difference at every point was calculated. Meanwhile, the positive and negative probe of the multimeter was connected to the TEG circuit using alligator clips. Two units of thermocouple were used to measure the temperature at both the hot and cold side of the TEG. The measurement only conducted at one unit of TEG mainly nearest to the heat source. Detail arrangement of TEGs on the copper plate and temperature measurement location are shown in Fig. 4. Data have been collected at every 10 seconds interval for a total of 200 seconds from the moment copper plate been heated. The specifications of both the digital multimeter and the dual-channel thermometer are as shown in Table-I.

Table-I: Equipment specifications for the test

Components	PART NAME/ MANUFACTURER	Rating values
Dual Channel Thermocouple	Temperature range Accuracy	-50°C – 1300°C ±0.1°C
Digital Multimeter DT830B	DC Voltage Range DC Current Range	200mV – 1000V 200µA – 200mA

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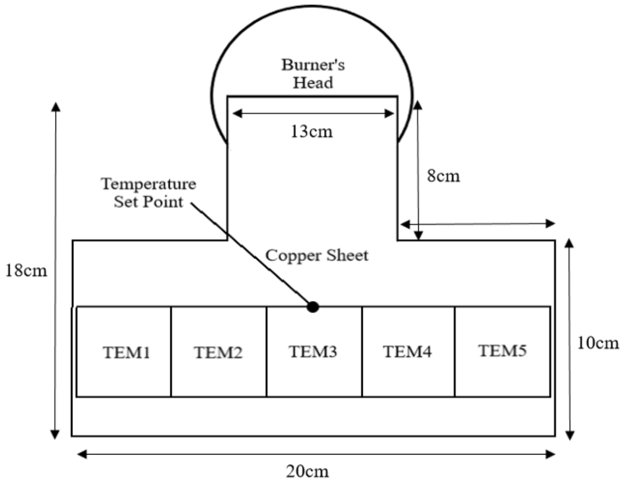

Fig. 4. Top view arrangement of TEG and temperature set point

IV. RESULTS AND DISCUSSION

The steepness of voltage increment and the time taken to become stable is very much depending on the heat source used. A bigger amount of excess heat released from its source will further increase the steepness of the slope and faster time taken to become stable. Even though the measurement was taken from the moment the copper plate been heated, however, the temperature only becomes stable somewhere at 80 seconds. Therefore, the analysis will only be focused at this point onwards.

A. Waste heat availability and temperature difference characteristic

Table-II shows the results of both temperatures at the hot and cold section as well as the calculated temperature difference for the range of 80 – 200 sec heating time.

The trend shows that the temperatures at the hot side of the TEG modules (Fig. 5) increase as the heating time increase even after 200 seconds. The average increment at every 10 seconds was between 2~5°C. The highest temperature recorded at the hot side was up to 97.3°C. The trend of T_{hot} graph which keeps on increasing shows that waste heat availability is not yet achieved the maximum level. Further, the cold side temperature shows almost similar trend as the hot side (Fig. 5) where both are almost parallel. The temperature range at the cold side was between 45.9~76.6°C. This is relatively still high as compared to the room temperature (23.6~25.2°C). Therefore, it can be further dropped by means of cooling mechanism, hence contribute to an increase in temperature difference.

Table-II: Temperature of the hot and cold section of the TEG and the temperature difference

Time (sec)	T_{hot} (°C)	T_{cold} (°C)	ΔT (°C)
80	72.3	45.9	26.4
90	75.9	49.8	26.1
100	66.9	54.0	12.9
110	72.2	57.1	15.1
120	76.9	57.3	19.6
130	79.3	62.0	17.3
140	82.0	65.0	17.0
150	84.7	66.0	18.7
160	85.9	69.5	16.4
170	92.6	71.6	21.0
180	93.7	73.8	19.9
190	95.7	75.0	20.7
200	97.3	76.6	20.7

The temperature difference between the hot and cold side of the TEG as shown in Fig. 5 is relatively almost constant over time with an average value of only 17.7°C. Datasheet of this TEG stated that it is able to achieve temperature different up to 100°C [21]. A group of researchers using four units of the same TEG [22] able to achieve temperature different up to 63°C at 105°C hot side temperature. The cold side of the experiment was equipped with a heat pipe sink. Table-III shows the overall comparisons of the measured temperatures.

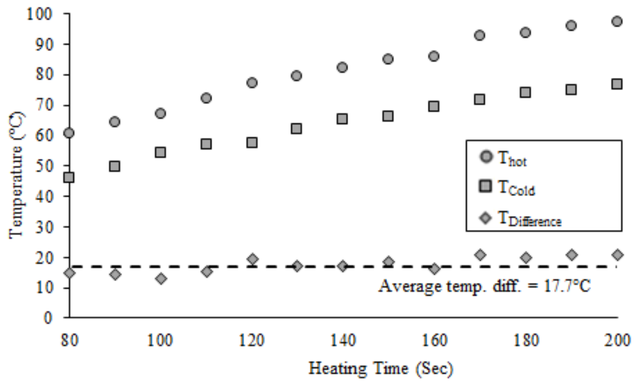

Fig. 5. The temperature at TEG over heating time.

Table-III: Comparison with other researchers with the same TEG unit

No. of TEG used	T_{hot} (°C)	T_{cold} (°C)	ΔT (°C)
4 [22]	105	42	63
5	97.3	76.6	20.7

Temperature difference shows a straight forward indicator of the TEG capability in converting heat. The higher the difference shows the bigger amount of heat been converted into electrical energy. An increase in the number of TEG will further enhance the conversion process as shown in [22]. By increasing the number of TEG, more waste heat will be collected and converted. This can be further improved by adding a cooling mechanism at the cold side [22]. Since the contact area is one of the heat transfer parameters, therefore, an additional number of TEG on the copper plate will increase the contact area [15].

B. Energy conversion performance

The voltage and current output measured as well as the calculated power output are shown in Table-IV. All outputs had increased uniformly over time (Fig. 6) and achieved the maximum at around 90 seconds before slowly decrease until the end of the experiment. The trend was also recorded in [14] which very much related to the Seebeck effect. The maximum values recorded for voltage, current and power output are 1.12 V, 42.1 mA and 46.8 mW respectively.

Fig. 7 further shows the range of temperature different where the high energy conversion takes place between 12.9~26.4°C. Within this range, the average voltage, current and power output generated are 1.07 V, 38.6 mA and 41.3 mW respectively.

Table-IV: Output values from the TEG modules

Time (sec)	ΔT (°C)	V (V)	I (mA)	P (mW)
0	2.6	0.01	0	0.0
10	3.8	0.11	2.1	0.2
20	6.5	0.28	7.5	2.1
30	10	0.47	13.7	6.4
40	11.4	0.66	22.9	15.1
50	11.4	0.86	29.7	25.5
60	22.4	0.99	36.1	35.7
70	23.1	1.06	40.1	42.5
80	26.4	1.11	41.7	46.3
90	26.1	**1.12**	41.8	**46.8**
100	12.9	1.11	**42.1**	46.7
110	15.1	1.09	41.7	45.5
120	19.6	1.09	40.4	44.0
130	17.3	1.08	40.1	43.3
140	17	1.08	38.3	41.4
150	18.7	1.07	37.4	40.0
160	16.4	1.06	36.9	39.1
170	21	1.06	36.8	39.0
180	19.9	1.05	36.3	38.1
190	20.7	1.04	35.3	36.7
200	20.7	1.01	34.4	34.7

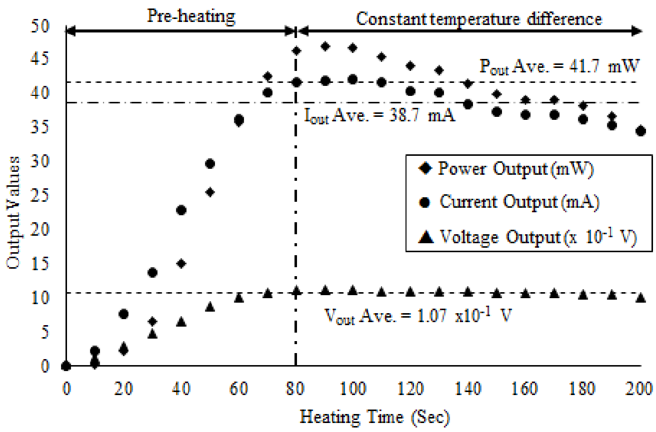

Fig. 6. Output values over heating time.

Since the conversion performance is very much depending on the temperature difference, Fig. 7 shows the analysis of the relationship between the output values with the temperature different. It shows that the output values are almost constant between the temperature differences of 13.0°C to 26.0°C. This is the range where high energy conversion takes place. Therefore, it is necessary to maintain the temperature difference at a certain high value in order to produce higher outputs. For this study, the average and maximum of the output values are summarized in Table-V.

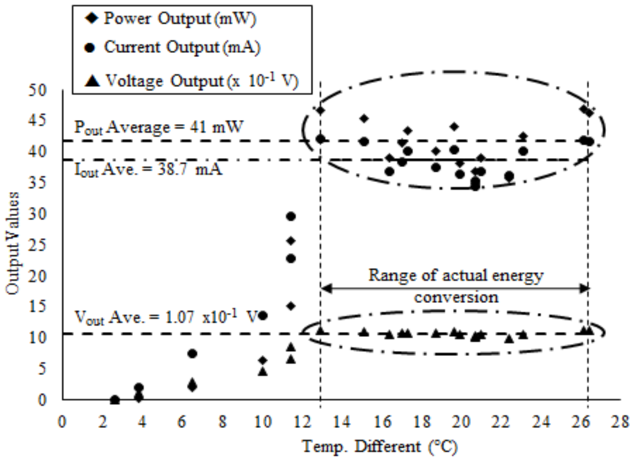

Fig. 7. Range of high energy conversion over temperature difference.

Table-V: Maximum and average values of the output

Output Values	Average values	Maximum values
Voltage (V)	1.07	1.12
Current (mA)	38.6	42.1
Power (mW)	41.3	46.8

C. Characteristic of Seebeck effects

Seebeck characteristics, in this case, is based on the equation (3). The calculated Seebeck values along the constant temperature range are shown in Table-VI. The trend shows that the coefficient is reducing (refer Fig. 8 and 9) for both over heating time and temperature different [14] due to the characteristic of the semi-monomer material used in constructing the TEG modules. The reduction is about 4 mV/°C for every one-unit temperature difference and 0.2 mV/s for every 1 sec. heating increment. This is the reason where the outputs values also slowly dropped over time (refer to Fig. 6).

$$\alpha_{TEG} = \frac{V_O}{T_{hot} - T_{cold}} \quad (3)$$

Table-VI: Calculated Seebeck coefficient

Time (sec)	ΔT (°C)	V (V)	Seebeck (x 10^{-3} V/°C)
80	26.4	1.11	42.0
90	26.1	1.12	42.9
100	12.9	1.11	86.0
110	15.1	1.09	72.2
120	19.6	1.09	55.6
130	17.3	1.08	62.4
140	17	1.08	63.5
150	18.7	1.07	57.2
160	16.4	1.06	64.6
170	21	1.06	50.5
180	19.9	1.05	52.8
190	20.7	1.04	50.2

200	20.7	1.01	48.8

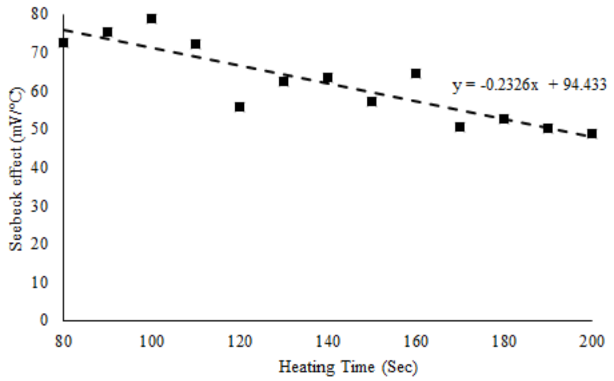

Fig. 8. The trend of Seebeck coefficient over heating time.

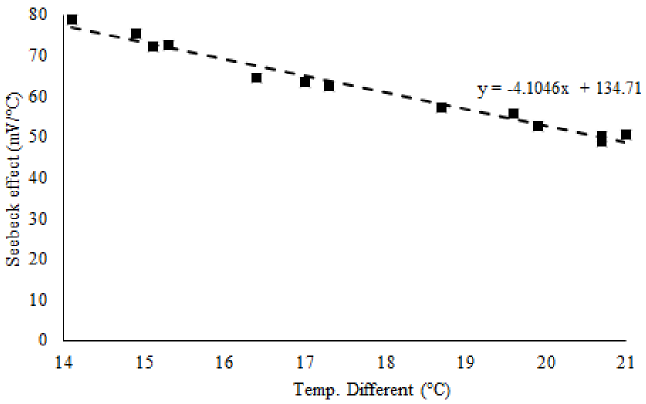

Fig. 9. The trend of Seebeck coefficient over temperature different.

V. CONCLUSION

The study has shown the feasibility of using excess heat from cooking activities as an alternative electrical energy source at night market by converting using TEG. The excess heat produced relatively high enough for the conversion and very much depends on the cooking period. The highest measured temperature received at hot side of the TEG from cooking stove was 97.3°C.

All three outputs namely voltage, current and power showed a similar pattern. However, due to very low current produce, the average calculated power produced was only 46.8 mW. Since the excess heat is still available, therefore an increase in number of TEG [23] will further increase the power output as well as adopting cooling mechanism on the TEG [8]. However, decreasing in Seebeck coefficient over heating time will become drawbacks to the voltage generation.

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AUTHORS PROFILE

Mohd Arizam bin Abdul Wahap is a lecturer at Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia. He graduated from Universiti Teknologi Malaysia in BEng (Hons.) Mechanical Engineering (Marine Technology) in 2004. In 2013, he finished his MEng. in Manufacturing Engineering (Manufacturing Design System) from Universiti Teknikal Malaysia Melaka (UTeM). His research interest in renewable energy and marine design technology. He registered as a Professional Technologist (Ts.), Malaysia Board of Technology (MBOT).

Mohamad Haidir bin Maslan (PhD) is a senior lecturer at Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia. He graduated from Universiti Teknologi Malaysia in BEng (Hons.) Mechanical Engineering in 2004. In 2008, he finished his MEng. in Mechanical Engineering from Universiti Teknology Malaysia (UTM). In 2016, he finished his PhD in Mechanical Engineering from University of Manchester. His research interest in fracture mechanics and renewable energy.

Mohd Sharimienizam bin Harun graduated from Universiti Teknikal Malaysia Melaka (UTeM) in Bachelor Engineering Technology (Air Conditioning) in 2019.

Ts. Shahrizal Saat, Lecturer, Department of Electronic & Computer Engineering Technology, Faculty of Electrical & Electronic Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia. He obtains Bachelor Degree Electronic Engineering from Universiti Teknologi Malaysia (UTM), Malaysia and Master Degree Electrical Engineering from Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia. Field of interest in an embedded system and automation technology. He registered as a Professional Technologist (Ts.), Malaysia Board of Technology (MBOT).

ASR A SUBKI obtained his MSc in Microelectronics from Universiti Kebangsaan Malaysia in 2011. He has 2 years of working experience as Photolithography and Wet Etcing Process Engineer at ON Semiconductor Malaysia and as Process Integration Engineer at SilTerra Malaysia focusing on maintaining process parameters for CMOS 0.16 nm technology, before joining Universiti Teknikal Malaysia Melaka (UTeM) as lecturer and researcher, in Electronics and Computer Engineering. His research interests include CMOS process flow optimization, thin film fabrication and characterization and power electronic.