Cooking Waste Heat Energy Conversion Using Thermoelectric Generator, Enhanced With Forced Convection Water Cooled For Night Market Application

Abdul Wahap, Mohd Arizam, Othman, Muhammad Nur, Coomerasamy, Punethen, Salleh, Aiza Syuhaniz

Abstract: A night markets' hawkers use an electric lamp to light up their stalls. The current practice is by using a petrol electrical generator which had contributed to pollution and also gives an additional cost to the hawkers. There is an alternative electric source for those whose cooking is business-oriented. This research develops a Water-cooled thermoelectric generator to harvest excess heat from night market cooking activity. A maximum of 2.4 watts DC electric power has been generated using 10 units of TEG connected in series directed into a butane stove using a copper plate and enhanced with a flow of cooled water. This was equivalent to 9.2% efficiency of the heat conversion process. Analysis of the cooling effect showed that an amount of 8.5 kW heat successfully been removed from the cool side of the TEG using forced convection water cooling at 5.55 x 10^{-5} m^3/s flowrate.

Index Terms: butane stove, experimental analysis, forced convection, heat energy conversion, thermoelectric generator, water cooling, night market

1. INTRODUCTION

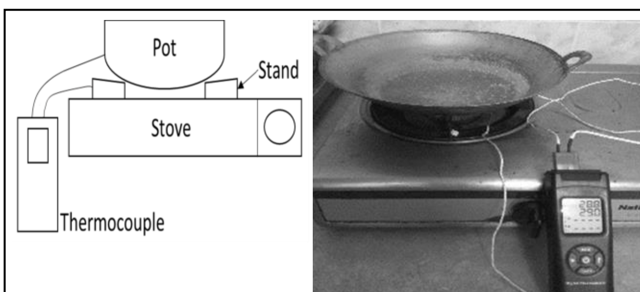
ELECTRICAL energy requirement at the Malaysian night market is very essential since stalls are opened along the temporarily closed road [1,2] where usually without electrical supply from the authorities. This therefore require the stall hawkers to use their own electrical source such as from internal combustion engine (ICE) petrol generator and wet or dry battery cells. A widely used electrical supply mainly comes from the ICE generator. Even though it able to supply enough amount of electrical energy, however, it also produces air and noise pollution [3]. A reliable electrical energy source is essential to ensure the smooth operation of the night market [4]. Alternatives electrical source [5,6] can be taken into consideration since the energy requirement at night market relatively low which majority just to light up fluorescent, halogen or LED bulb with an average of 20 to 30 watts. Further, their operation which requires electrical power is only within two to three hours on average. A thermoelectric generator (TEG) is known as non-moveable part heat to an electric generator, able to produce reliable electric power from various range of temperature source [7]. Night market with an average of 20~30% of hawkers [8] sell cooked food will involve cooking activities that normally use LPG stove and therefore can become the heat source. The voltage and current generated by TEG are DC type and therefore suitable and safe for application at the night market. The power generation is proportionate to the temperature difference between the hot and cold sides of the TEG. Based on the study conducted in [9], the temperature difference of the TEGs module is almost constant even though the temperature at the hot side increasing. Therefore, the focus of this study is to further increase the temperature difference by introducing a cooling mechanism. Few potential cooling approaches already been reported such as using heat sink [10], liquid cooling [11] or passive cooling [12] together with TEG and nano-fluid such as ethylene glycol [13].

- *Abdul Wahap, Mohd Arizam, is a lecturer in Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM). E-mail: arizam@utem.edu.my*
- *Othman, Muhammad Nur, is a lecturer in Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM).*
- *Coomerasamy, Punethen was graduated from Universiti Teknikal Malaysia Melaka (UTeM) in 2020.*
- *Salleh, Aiza Syuhaniz is a lecturer in Universiti Kuala Lumpur, Malaysian Institute of Chemical and Bio-Engineering Technology (UniKL MICET).*

2 METHODOLOGY

2.1 Selection of Heat Harvesting Location

The initial stage of the experiment was to determine the location where to harvest the heat. Two possible locations for heat harvesting were chosen which were at stand and at cooking utensils. A deep frying pan was used in this experiment since it is a common cooking utensil used at night market. The amount of heat available at these two location was measured using thermocouple as shown in Fig. 1. The heat was recorded until it becomes stable which up to 12 minutes. The ambient temperature recorded was 26°C. Two heat sources were used at this stage namely LPG stove which is normally used at night market and a butane stove which used for the next laboratory-scale experiment. It is important to harvest the heat from a source similar to the one used at night market. However, due to safety and easy handling purposes, the butane stove was selected for lab scale-experiment.



(a) (b)

***Fig. 1**. (a) Schematic diagram and (b) actual setup of determining heat harvesting location.*

2.2 Heat Conversion

The setup consists of 10 unit TEG (SP1848-27145), two 0.1 mm thick L-shaped copper plates, a butane stove, two W-shaped cooling blocks (refer fig. 2), a multimeter and two-unit multi-channel thermocouples. The TEG were connected in series and attached vertically on the copper plate (refer fig. 3) using thermal adhesive. Five unit TEG on each plate. The cooling blocks were then attached on the other surface of each five set TEG. Surface TEG attached to the cooper plate was set as a hot side while the other surface attached to the cooling block was set as a cooled side.

***Fig. 2**. Aluminum W-shaped cooling block used in the cooling process.*

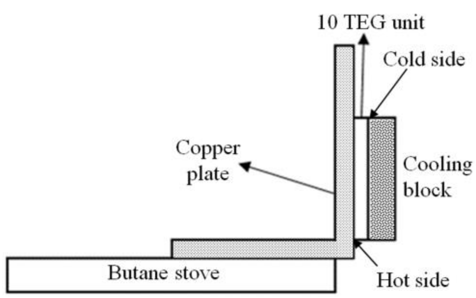


***Fig. 3**. Five set of TEGs attached vertically on an L-shaped copper plate.*

Six main parameters were measured namely temperature at hot (T_H) and cold (T_C) sides of the TEG, liquid cooling temperature for inlet (T_{CI}) and outlet (T_{CO}), DC voltage (V_O) and current (I_O). All parameters related to temperature were measured using two thermocouples. T_H and T_C were measured at the center of the five set TEG. Further, T_{CI} was measure inside the water tank while T_{CO} at the pipe outlet before into the drainage. The two electrical output parameters were measured using a multi-meter. All parameters were measured for a total of 220 seconds mainly up to a condition where the heat supply becomes stable. Fig. 5 shows the schematic diagram of the setup with a measuring location. The power generated (P_O) was calculated as in

$$P_O = I_O V_O \tag{1}$$

The performance of the TEG energy conversion then be estimated based on

$$\varepsilon = \frac{T_H - T_C}{T_H} \frac{\sqrt{1+ZT} - 1}{\sqrt{1+ZT} + \frac{T_C}{T_H}} \tag{2}$$

where ε is conversion efficiency and ZT is a figure of merit and taken to be 0.7 [14]. Cooling process performance was then analyzed using

$$Q_{water} = \dot{m} c_P (T_{CI} - T_{CO}) \tag{3}$$

where Q_{water} is the rate of heat absorbed during the cooling process, $\dot{m}$ is the cooling liquid mass flow rate and C_P is the specific heat of the water.

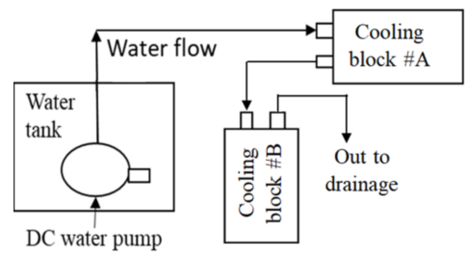


***Fig. 4**. Schematic diagram of the cooling process connection.*

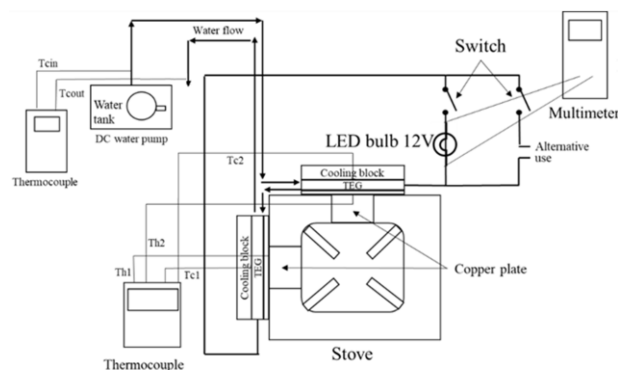


***Fig. 5**. Schematic diagram TEG connection with complete measurement points.*

3 RESULTS AND DISCUSSION

3.1 Selection of Heat Harvesting Location

The Heat source is very important in heat harvesting since it will determine the potential amount of energy generated by TEG. Based on the two selected locations, deep frying pan made of steel provides higher temperature as compared to stand for both LPG and butane stoves (refer table 1). Fig. 6 shows that temperatures become almost stable starting at four minutes and this gives an average temperature at frying pan for LPG and butane stove of 247°C and 202.8°C respectively. Different designs of the frying pan may contribute to different heat transfer processes [15]. Further, a larger contact area with the flame on the deep frying pan also contributes to the higher temperature recorded.

TABLE 1

COMPARISON OF HEAT AVAILABILITY AT STEEL DEEP FRYING PAN AND STAND FOR LPG AND BUTANE STOVE

Time	LPG Stove		Butane Stove	
(min)	Stand (°C)	Pan (°C)	Stand (°C)	Pan (°C)
0	34.2	33.4	28.7	28.6
1	111.3	207.5	133.3	133.1
2	161.9	228.7	165.2	176.9
3	185.9	231.9	188.1	190.7

4	213.5	240.9	198.1	245.8
5	228.0	260.1	202.8	245.5
6	227.9	232.7	204.5	225.3
7	237.7	236.0	209.1	215.4
8	244.6	246.2	205.2	220.9
9	233.1	246.5	201.7	216.9
10	242.4	251.1	202.4	223.9
11	235.6	247.4	201.5	230.1
12	245.2	262.3	199.9	235.2
Ave	234.2	247.0	202.8	228.8

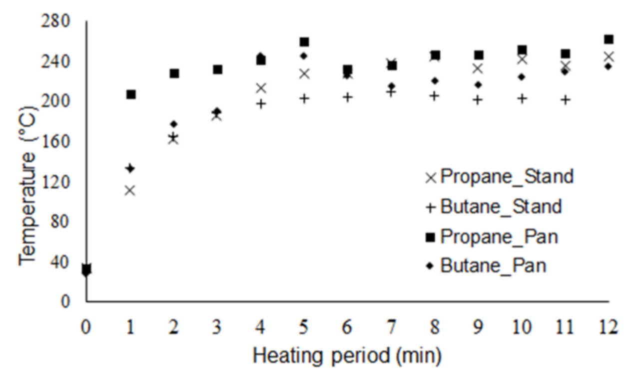


***Fig. 6**. Comparison of heat availability at deep steel frying pan and stand for LPG and butane stove.*

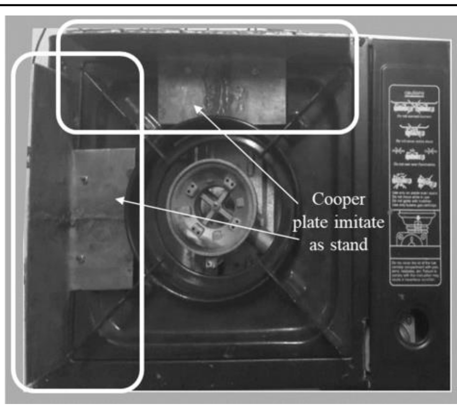


***Fig. 7**. Attachment of copper plate on butane stove using screw.*

Based on this data, the steel frying pan is considered a good location relative to stand for heat harvesting. However, the experiment setup was using the stand as the heat harvesting location due to the ease of connecting the copper plate (refer fig. 7) for the harvesting process. LPG contains 60%-70% propane and 30%-40% butane. Relatively, LPG has higher a calorific value as compare to butane alone. Therefore, LPG will produce higher heat energy [16] as shown in this experiment. Table 1 shows that temperature measured at both steel frying pan and stand recorded higher temperatures at all-time for LPG stove as compared to the butane stove.

3.2 Energy Conversion Performance

Results presented in Table 2 show that the recorded values increase over time. The electrical output parameters were analyzed over temperature different since it is the governing parameter for voltage generation. The voltage output becomes stable at a temperature difference of 35°C with an average value of 12.7 V as shown in Fig. 8. However, the current produced takes a longer time to stable at a temperature difference of 55°C with an average value of 185.8 mA. These situations have affected the power output since it is a product of voltage and current which gives an average value of 2.4 W.

TABLE 2
OUTPUT VALUES

Time (s)	Temp. Diff. (°C)	Voltage (V)	Current (mA)	Power (mW)
20	14.6	5.02	0.10	0.50
40	18.2	7.45	10.50	78.23
60	24.8	8.90	19.70	175.33
80	29.6	10.05	48.70	489.44
100	32.3	11.26	68.74	774.01
120	34.8	11.91	75.38	897.78
140	37.6	12.10	84.35	1020.64
150	40.4	12.30	95.47	1174.28
160	44.0	12.64	110.7	1399.25
170	49.1	12.96	120.97	1567.77
180	51.5	12.94	140.65	1820.01
190	53.9	12.98	160.87	2088.09
200	55.8	13.10	187.38	2454.68
210	58.0	13.05	185.6	2422.08
220	59.5	13.16	184.35	2426.05

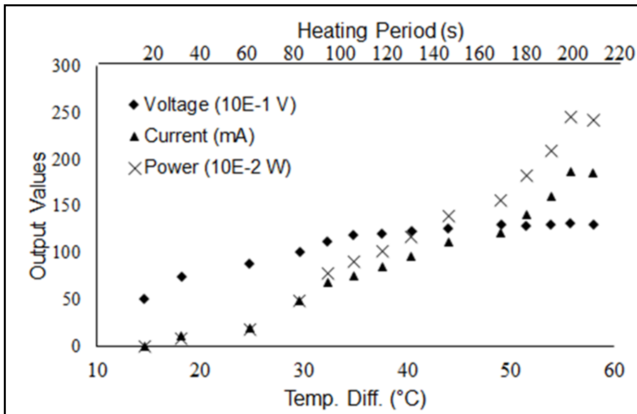


***Fig. 8**. Output values over temperature different and heating period.*

The calculated efficiency of the energy conversion process was between 4.3% to 9.2%. A comparison has been made with the same application of five units TEG published in [9] where the efficiency is between 2.7 to 5.7%. Comparison of the temperature difference for TEG with and without cooling depicted in fig. 9 also shows that cooling gives significant increment in temperature different thus contribute to better electrical outputs.

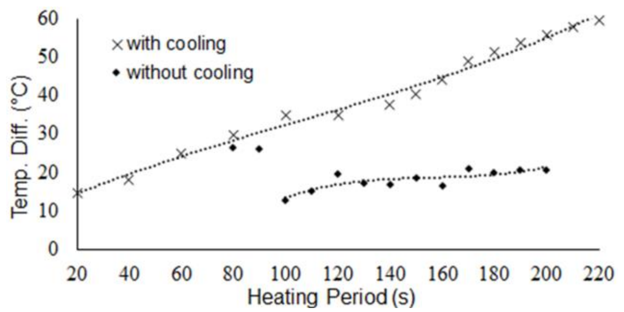


Fig. 9*. Effect of cooling process on temperature different.*

3.3 Cooling Effect Analysis

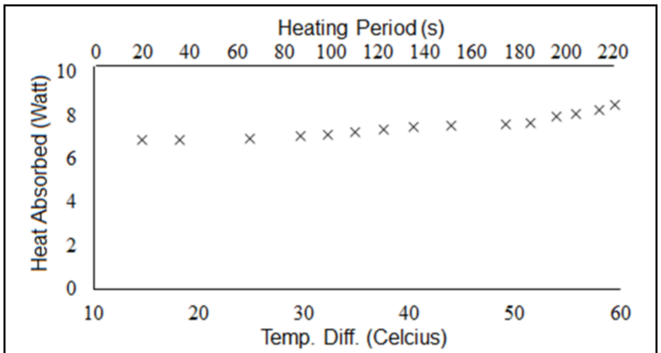


Fig. 10*. Performance of the cooling process over temperature different and heating period.*

TABLE 3

PERFORMANCE OF COOLING PROCESS

Time (s)	ΔT TEG (°C)	T_{CI} (°C)	T_{CO} (°C)	ΔT Cooling (°C)	Q (kW)
20	14.6	30.1	30.5	0.4	6.9
40	18.2	30.1	30.6	0.5	6.9
60	24.8	30.2	30.8	0.6	6.9
80	29.6	30.9	31.1	0.2	7.0
100	32.3	31.2	31.7	0.5	7.1
120	34.8	31.3	32.6	1.3	7.3
140	37.6	31.9	33.1	1.2	7.4
150	40.4	32.4	33.6	1.2	7.5
160	44.0	32.6	33.9	1.3	7.5
170	49.1	32.7	34.5	1.8	7.6
180	51.5	33.0	34.9	1.9	7.7
190	53.9	34.7	35.8	1.1	8.0
200	55.8	34.9	36.7	1.8	8.1
210	58.0	35.5	37.8	2.3	8.3
220	59.5	36.7	38.5	1.8	8.5

Fig. 10 shows that the rate of heat been absorbed from the TEG is increasing over heating time and TEG temperature different between 6.9 kW to 8.5 kW. Table 3 shows that the temperatures increment in water temperature after passing through the cooling block are between 0.4°C up to 2.3°C. These are relatively low as compared to other nano-fluid such as ethylene glycol [17]. As for comparison, the specific heat capacity of ethylene glycol is 2415 J/kg.K, while for water is 4179 J/kg.K. By principal, it is expected that ethylene glycol may remove heat with more efficient. Further, mixing of nano-fluid with water at a dedicated ratio will further enhance the heat absorption process [18].

5 CONCLUSIONS

Analysis of waste heat to electrical energy conversion using TEG enhanced with forced convection water cooling was successfully investigated and analyzed. The output generated were analzsed and compare its efficiency with the same unit TEG. The effectiveness of the cooling process was also discussed experimentally and theoretically. Several conclusions can be drawn based on the finding.

1. Heat conversion using TEG based on the waste heat from the cooking activity at night market has good potential to become an alternative energy source for night market hawkers. This is based on the amount of heat available and the targeted electrical power output which relatively low.
2. The cooling process will increase the power generated. However, selection of suitable cooling process is necessary because it may require additional energy source such as water pump. Therefore, an optimisation study of power produced and usage is necessary.

ACKNOWLEDGMENT

The authors would like to acknowledge the reviewer(s) for the helpful advice and comments provided. The authors wish to thank the Universiti Teknikal Malaysia Melaka (UTeM) for the financial support of this publication.

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