

Study On The Energy Conversion In The Thermoelectric Liquefied Petroleum Gas Cooking Stove With Different Cooling Methods

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Abstract - Thermoelectric materials can produce electricity from the waste heat from any sources, including a Liquefied Petroleum Gas (LPG) cooking stove. This study's objective was to investigate the effect of different cooling systems, including the heatsink, heatsink+fan, and waterblock on the energy absorbed by TEG, which is converted into electrical power output. The LPG cooking stove's pan support was modified using a steel plate that can adopt 4 TEG sites in series. The temperature measurement was conducted using thermocouples, which recorded using a data acquisition programmed by Arduino. The result showed that the heat energy absorbed by the water block is higher than that of the heatsink+fan and heatsink only. As a consequence, the net power output of the thermoelectric LPG stove, which was applied by the water block, is higher than that of the one using heatsink+fan and heatsink only. The power out obtained by calculation shows a close result with that obtained by measurement. This work has shown that the installment of the thermoelectric module on the LPG cooking stove can provide an alternative technique to reduce the heat loss from waste heat.

Keywords — Thermoelectric, LPG cooking stove, cooling methods, energy balance, power output.

I. INTRODUCTION

The energy crisis has made more than 1.2 billion people in the world living without access to electricity networks or lack of electrical energy, especially in developing countries [1][2]. Many efforts have been done to explore the potential of energy generation from alternative energy sources [3][4]. In some countries, LPG-fueled gas stoves were successfully implemented to replace the use of kerosene as the main stove fuel [5]. However, only 66% of the heat energy released by the combustion process of the gas is utilized for cooking, while the rest is wasted into the environment in the form of waste heat. It is then necessary to increase the utilization of the heat energy from the gas

combustion [6]. A thermoelectric generator (TEG) module has attracted big attention among researchers for an electrical energy generator that utilizes waste heat from industrial and household waste [7][8]. The use of TEG offers many advantages as it is environmentally friendly, weather independent, easy to operate, no vibrations, and no moving parts [9]. The TEG works by converting the heat energy into electrical energy based on a principle called the "Seebeck" effect, where the temperature difference between the hot and cold sides of the TEG module is converted into electrical voltage difference [10][11]. There are three main components of the TEG module, namely the Hot-side Heat-exchanger (HHX), thermoelectric module, and the cold-side heat exchanger (CHX) as the cooling system. To maximize the overall performance of the device, these three components must be considered [12]. The cold-side heat exchanger (CHX) in the TEG system transfers energy from the cold side of the TEG module to the environment. The effective design of CHX then becomes one of the important factors affecting the temperature difference between the hot and cold sides of the TEG module [13][14]. However, the problem arises when the hot-side of the TEG module absorbed the heat from the external source causes the cold-side of the TEG module to become hot too. This is due to the characteristic of the semiconductor materials built. The TEG module usually has linear electric conductivity and heat conductivity. This means that if the material has good electrical conductivity, it has a good thermal conductivity as well. This property leads to the reduction of the temperature difference between the two sides of the TEG module which then causes a decrease in the electrical power generated by the TEG. To obtain a big temperature difference between the hot and cold sides of the TEG module, the temperature of the TEG cold-side must be as low as possible [15].

Many studies investigating the cooling system of the TEG module have been carried out to improve the TEG performance. In general, four design concepts for cooling



methods were used in the TEG technology, including a normal air cooling system, forced air cooling system, cooling water system, and a forced-air cooling system [16]. Jiming et al. studied the cooling system of a small-scale TEG module to reduce the consumption of dry (non-rechargeable) batteries of an electric generator. The device was designed based on the loop-thermosiphon principle to provide effective cooling in a short time (~15 minutes) [17]. The system operated automatically without a fan and pump, and there is no need for maintenance. It was demonstrated that the cooling efficiency was higher than that using air-cooled natural convection. Yousef et al. examined the cooling system of the TEG module in the charcoal furnace use of heat exchanger fins, which were placed on the cold-side of the TEG module [18]. The cooling system was considered ineffective because the heat absorbed by the cooling system is relatively small. Montecuccio et al. applied a water block to reduce the cold-side temperature of the TEG module in a furnace with solid fuel (charcoal, coal, briquettes) [19]. It was shown that an average TEG output of 27 Watts was produced by a temperature difference of the TEG module of 250 °C. However, the water tank volume of 60 liters needs large dimensions. Robel et al. conducted a study on cooling systems of the TEG surface based on self-cooling systems [20]. The effect of the self-cooling system on the efficiency of the heat dissipation compared to the heat sink systems. The self-cooling system was carried out by adding a fan to the heat sink whose power source was obtained from the TEG output. It was shown that the highest heat temperature in the cold-side of the TEG module could be reduced by 20-40% when compared to that without using the fan. Dhruv et al. conducted a comparative study on the effect of using nanofluids Ethylene Glycol-water, MgO, ZnO as cooling media on the performance of TEG [12]. The highest power output produced by the TEG system could be increased by 11.38% by using 1% MgO nanofluid at an inlet temperature of 500 K. Pawatwong et al. [16] have examined the performance of an LPG gas stove with an aluminum plate heat sink for the cooling system combined with a fan. It was shown that at the temperature of the hot-side of TEG 130 °C, electric power of 9.8 Watt could be produced by the TEG temperature difference of 65 °C. In the same group, Lertsatitthanakorn et al. examined the electrical performance, economic evaluation, and energy conversion of a TE-LPG cooking stove. A windshield was used to protect against wind flowing to the cooker-top burner, which also served as the hot side of the TE modules [21]. A heatsink and fan were installed on the cold side of the TE modules. Although many studies have used heatsink as the cooling method of the TEG system, few studies analyze the energy balance in the combustion chamber of the gas stove. The objective of this work was to study the effect of different cooling methods on the energy balance and the power output of the

thermoelectric LPG cooking stove. The heat absorbed by TEG, which was installed by different cooling methods, was compared. A calculation method was conducted to predict the power output of the TE-LPG stove system.

II. THEORETICAL CONSIDERATIONS

A thermoelectric generator works when there is a temperature difference between the two sides of the TEG module, which is then converted into electrical energy based on the Seebeck effect. The basic principle of thermoelectricity can be seen in Fig. 1. The main parts of a thermoelectric generator are the heat exchanger, TE module, and heat sink. The electric power generated by the TEG module is influenced by the temperature difference on both sides of the TEG surfaces (hot side & cold side), the thermoelement dimensions, and the Seebeck constant of the TEG constituent material. A good thermoelectric material must have a high Seebeck constant, high electrical conductivity, and low thermal conductivity. One of the TEG constituent materials that are widely available in the market today is bismuth telluride (Bi_2Te_3). This material works at a maximum temperature of 380 °C and has a fairly low electrical resistance and material conductivity [22].

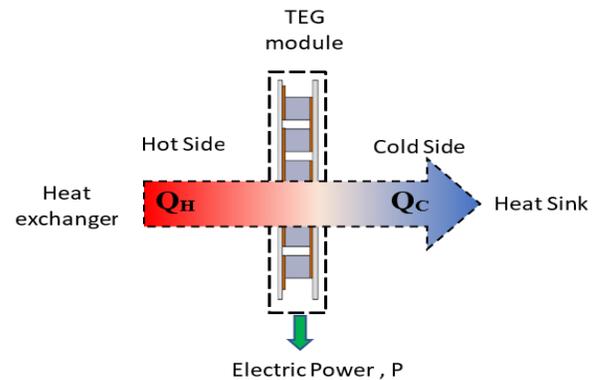


Fig. 1. Work principle of the thermoelectric generator

A. Energy balance in the combustion chamber

When a TEG system is applied to an LPG stove, it is required to observe the energy balance of the TEG stove system, as given in Fig. 2. The energy balance of the combustor is described in equation (1) and (2).

$$Q_{in} = Q_{out} \tag{1}$$

$$Q_a + Q_{LPG} = Q_{flame} + Q_{loss} \tag{2}$$

Where Q_a is the energy brought by the air, Q_{LPG} is the energy provided by the LPG gas, Q_{wall} is the energy loss to the combustion wall, Q_{gas} is the energy released by the gas flame, and Q_{TEG} is the energy used by the TEG system. Q_a is neglected with an assumption that the sensible in the air was very small [18]. Q_{LPG} is the energy released by the combustion of the LPG gas in the combustion chamber. In this study, it was assumed that the remained energy was Q_{loss} , which went to the wall of the combustion chamber. However, only a part of the energy from LPG combustion

can be utilized, so it is necessary to consider the heat emitted through the flow of gas and the heat absorbed by the walls of the combustion chamber (μ_c), including the heat used by TEG.

$$\mu_c \cdot Q_{LPG} = Q_{flame} + (Q_{wall} + Q_{TEG}) \quad (3)$$

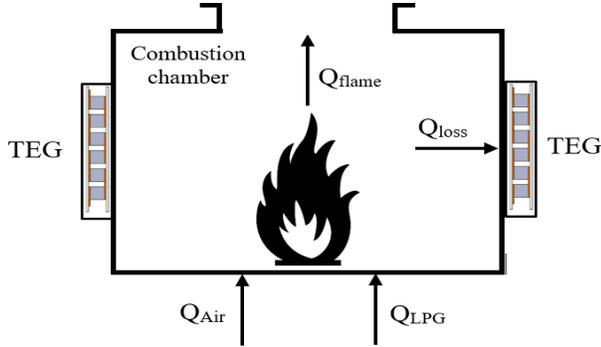


Fig. 2. The schematic of energy balance at the combustion chamber of the LPG stove

The calculation of the energy balance was carried out to determine the efficiency of gas combustion on the stove with the TEG installation. For this reason, it is necessary to calculate all forms of energy that are in equilibrium in the combustion chamber, namely Q_{LPG} , Q_{wall} , Q_{flame} , and Q_{TEG} . The temperature measured at the combustion wall (T_s) was used as a reference for calculating Q_{LPG} , Q_{wall} , Q_{flame} , and Q_{TEG} .

a) Q_{LPG}

The energy provided by LPG gas can be calculated using equation (4).

$$Q_{LPG} = \dot{m}_{LPG} \cdot LHV \quad (4)$$

The mass flow rate of the gas, \dot{m}_{LPG} was determined by measuring the weight of the before and after utilization for a given time.

b) Q_{wall}

The energy released by the combustion of the LPG gas was used for cooking partly and lost to the wall of the chamber. To calculate the Q_{wall} , it is required to consider the energy balance at the wall of the combustion chamber, as described in Fig. 3.

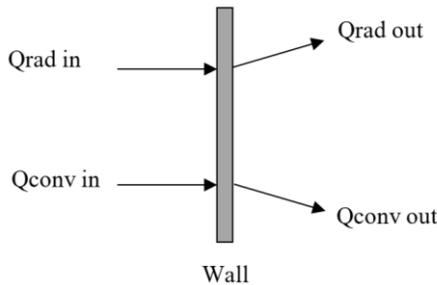


Fig. 3. Energy balance at the combustion wall

$$Q_{wall.in} = Q_{wall.out} \quad (5)$$

$$Q_{rad.in} + Q_{conv.in} = Q_{conv.out} + Q_{rad.out} \quad (6)$$

$$h_{in} A_1(T_f - T_s) + \epsilon_f \sigma A_1(T_f^4) = h_o A_1(T_s - T_a) + \epsilon \sigma A_1(T_s^4 - T_a^4) \quad (7)$$

c) Q_{flame}

The energy of the gas flame, Q_{flame} , is calculated using equation (8).

$$Q_{flame} = \dot{m}_f C p_f (T_f - T_a) \quad (8)$$

To calculate the energy which is used for cooking, it is required to determine the mass flow rate of the gas by considering the *Air-Fuel Ratio*, A/F as mentioned in equation (9) and (10).

$$\dot{m}_f = \dot{m}_{LPG} + \dot{m}_a \quad (9)$$

$$\left(\frac{Air}{Fuel}\right)_{stoich} = \left(\frac{\dot{m}_a}{\dot{m}_{LPG}}\right)_{stoich} \quad (10)$$

For LPG, $\left(\frac{Air}{Fuel}\right)_{stoich} = 15.67$ [23]

d) Q_{TEG}

The energy used by the TEG module installed on the wall can be calculated using equation (11).

$$Q_{TEG} = Q_{rad.in} + Q_{conv.in} \quad (11)$$

$$Q_{TEG} = h_i A_2(T_f - T_s) + \epsilon_f \sigma A_2(T_f^4) \quad (12)$$

B. Electrical performance of thermoelectric systems

After determining the energy balance that occurred in the gas stove and the amount of heat energy entering the stove wall in which the TEG is installed, it is then necessary to calculate the heat that was converted into electrical energy. Fig. 5 shows the electrical circuit of the TEG system with an external load of a DC lamp. The calculation of the TEG performance is carried out using equation (13)-(15).

The electric current flowing through the TEG system circuit:

$$I = a \cdot \Delta T / (R_i + R_L) = V_{oc} / 2R_i \quad (13)$$

The maximum power produced by TEG:

$$P_{max} = N I^2 R_L = N \frac{a^2 (T_H - T_C)^2}{4R_L} \quad (14)$$

The output voltage of the TEG system with an external load of a DC lamp:

$$V_{cc} = \frac{P}{I} \quad (15)$$

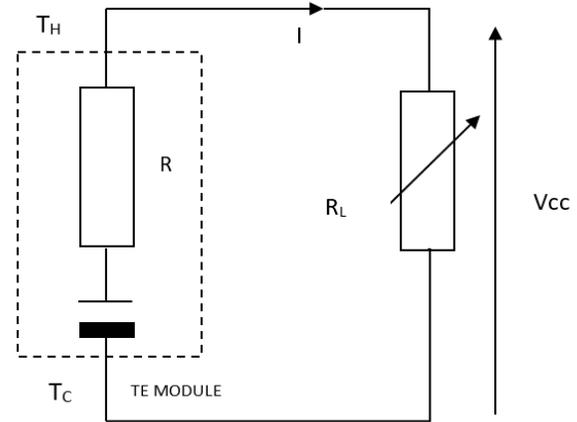
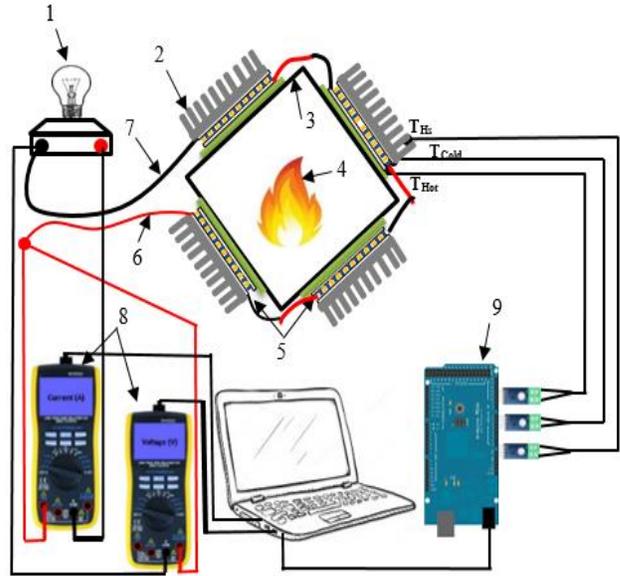


Fig. 4. Closed-circuit of the TEG system with a DC lamp

III. EXPERIMENTAL METHODS

Fig. 6 shows the schematic figure of the experimental tools, which mainly consist of the LPG stove, 4 TEG modules with aluminum heat sinks, a DC lamp, temperature measurement tools, and electrical performance tools. Fig. 7(a) and 7(b) show the LPG stove and the modified pan support, respectively. The stove wall in the pan support was made of commercial carbon steel with a 6 mm thickness. There are 4 TEG modules attached to the outside of the stove wall and connected in series. The specification of the TEG module is given in Table 1. The hot side of the TEG modules was attached directly to the stove wall, whereas different cooling tools were installed in the cold side of the TEG, which includes a heat sink, heatsink+fan, and water block. The heatsink represents air-cooled natural convection. The heatsink+fan denotes air-cooled forced convection, where an additional cooling of the heatsink is provided by a fan. The water block designates the water-cooled forced convection, which is carried out using a cooling block and a pump system [15]. To operate the water block, an additional pump of 1 Watt supplied by external power was needed. For the heatsink+fan, a heatsink was combined with a pump that requires a 0.5 Watt power supply. Fig. 8 shows the schematic figure of the heat sink, heatsink+fan, and water block. The dimension of the aluminum heatsink is 50 mm in width, 50 mm in length, and 40 mm in thickness. The size of the width, length, and thickness of the water block is 40 mm, 40 mm, and 12 mm, respectively.

The hot side of the TEG modules was heated up by the combustion flame of the LPG gas. The parameters of the LPG gas combustion in the combustion chamber are given in Table 2. For the temperature measurement, some K-thermocouples were installed in the hot side of the TEG (T_{Hot}), the cold side of the TEG (T_{Cold}), and the fin of the heat sink (T_{HS}). To acquire the online monitoring of the temperature data, a data logger was made by an Arduino Mega 2560 type, which is assembled with 4 temperature sensors of Max6675 type. The block diagram in Fig. 6 shows the process of converting a temperature signal from analog to digital. The temperature signal detected by the K thermocouple is still in the form of micro-voltage (μV), which is then converted and amplified by the Max6675 sensor into digital data. Signal processing was then carried out by Atmega2560 so it can be displayed on a PC screen in the form of real-time data. In addition to the measured data of the power output, a calculation was also carried out. Table 3 shows the parameters used to calculate the power output of the thermoelectric LPG stove systems.



Description:
 1. DC lamp
 2. Heatsink
 3. Gas stove wall
 4. Heat source
 5. TEG assembly
 6. Positive TEG wire (+)
 7. Negative TEG wire (-)
 8. Multimeter USB
 9. Arduino temperature data logger

Fig. 5. Experimental set up in the thermoelectric LPG cookstove for heatsink

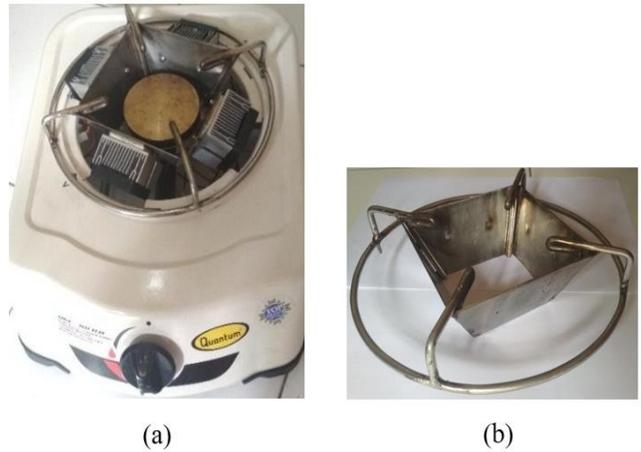


Fig. 6. (a) The LPG stove installed by 4 TEG modules, and (b) Modified pan support

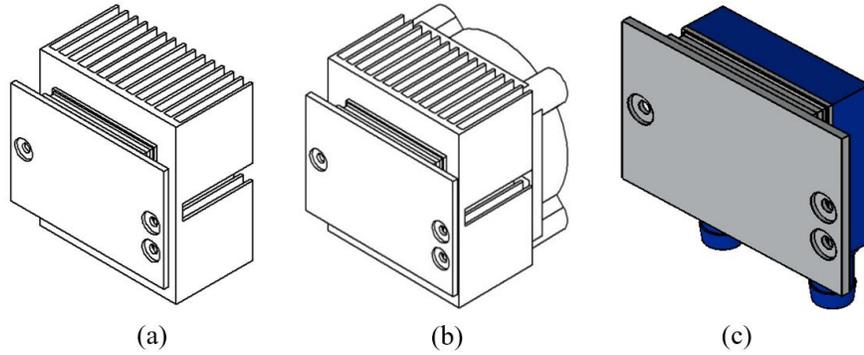


Fig. 7. Schematic figure of: (a) heat sink, (b) heatsink+fan, (c) waterblock

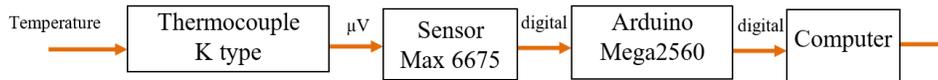


Fig. 8. The block diagram of the temperature measurement

Table 1. Specification of the TEG module

Parameter	Description
Dimension:	
a. Length	40 mm
b. Width	40 mm
c. Thickness	3.8 mm
d. Mass	25 gram
Material	
a. Material hot side & cold side TEG	Ceramic
b. Positive semiconductor (P-leg)	Bi ₂ Te ₃
c. Negative semiconductor (N-leg)	Bi ₂ Te ₃
Physical parameters:	
a. Coefficient of Seebeck	0.054 V/K
b. Thermal conductivity	-
c. Electric conductivity	0.6 W/m.K
d. Number of semiconductors	12
e. Maximum temperature of work	300 °C
Manufacturing by	Shenzhen Ruised Technology Co., Ltd
Manufacturer Address	Ghuangdong, China

Table 2. Parameters of the gas combustion

Physical parameters	Value	Unit	Ref.
The coefficient of the convection heat transfer inside of the stove wall (h_i)	10	W/m ² .K	[18]
The coefficient of the convection heat transfer outside of the stove wall (h_o)	100	W/m ² .K	[24]
Area of the combustion chamber wall without TEG (A_1)	0.0209	m ²	
Area of the combustion chamber wall covered by TEG (A_2)	0.0064	m ²	
The emissivity of gas flame (ϵ_f)	0.061		[25]
The emissivity of the wall (ϵ_w)	0.85		[26]
Constant of Stefan Boltzmann (σ)	5.67 x 10 ⁻⁸	W/m ² K ⁴	[18]
Specific heat capacity of gas flame, cp_f	1.480	kJ/Kg.K	[27]

The low heating value of gas (LHV)	46607	kJ/kg	[28]
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Table 3. Electrical parameters of the TEG systems

Parameters	Value	Unit	Ref.
Seebeck effect of Bi ₂ Te ₃ , <i>a</i>	0.054	V/K	[29]
The internal resistance of TEG systems, <i>R_i</i>	5	Ohm	[29]
The electrical resistance of the DC lamp, <i>R_L</i>	10	Ohm	
Number of TEG module, <i>N</i>	4		

IV. RESULTS AND DISCUSSION

A. Energy balance in the combustion chamber

To study the heat transfer in the TEG stove system, the temperature measurements were carried out to observe the temperature of the hot side and cold side of the TEG and the temperature of the heat sink. Fig. 8 shows the temperature profile observed on the hot side and the temperature difference of the TEG during 10 minutes. The temperature of the cold side is not displayed in the graph to avoid a meshed curve appearance. The temperature monitoring was only conducted for only 10 minutes as the temperature difference of the hot and cold sides of the TEG was almost stable after the stove operated at approximately 350 seconds. Based on this temperature point, the average temperature of the TEG hot side and the temperature difference during the steady-state is given in Table 2. The fin temperature was measured in the experimental work. It is not displayed in the figure. As a result, it was closely similar to that of the TEG cold side.

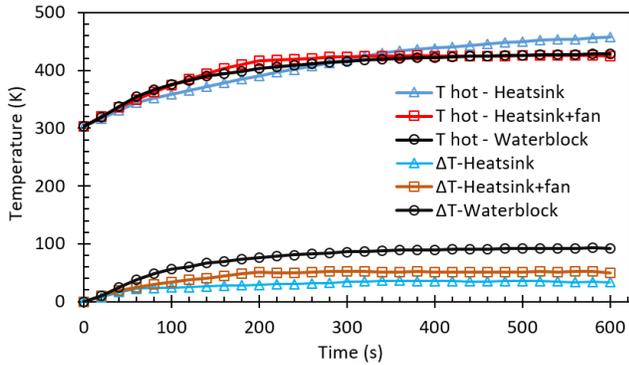


Fig. 9. The temperature profile of the *T_{hot}* and *T_{diff}* during the stove operation for 10 minutes using: heatsink, heatsink+fan, and water block

Table 2. The average temperature on the hot side and cold side of the TEG plate

Cooling methods	<i>T_{hot}</i> (K)	<i>T_{cold}</i> (K)	<i>T_{diff}</i> (K)
Heatsink	446.40	411.39	35.01
Heatsink + fan	423.98	372.59	51.39
Waterblock	423.25	333.33	89.92

Table 2 demonstrates that the different cooling methods significantly affected the temperature of the TEG hot side and cold side. The application of heatsink, heatsink+fan, and waterblock have sequentially resulted in a decrease in the temperature of the TEG hot side and the temperature difference. However, the gradient increase in the temperature difference is higher than that of the hot side temperature. This indicates that the heat absorbed by the water block is higher than that by heatsink and heatsink+fan. To determine the effect of different cooling methods on the used energy by TEG, the calculation of the heat balance in the combustion chamber is conducted using equation (1)-(12) using the data given in Table 2. Firstly, the calculation is carried out on the stove with a heatsink. The result of this calculation is used for comparison reference to other cooling methods.

a) Energy inputted by LPG gas, *Q_{LPG}*

$$Q_{LPG} = \dot{m}_{LPG} \cdot LHV$$

Although the temperature measurement was conducted for 10 minutes, the experiment was carried out for 60 minutes with a fixed gas flow rate. The gas consumption during 60 minutes of the stove operation was obtained by subtracting the weight of the gas bottle before and after utilization.

$$\dot{m}_{LPG} = 7.515 \text{ kg} - 7.395 \text{ kg} = 0.12 \text{ kg}/60 \text{ minutes} = 0.12$$

$$\text{kg}/3600 \text{ s} = 3.3 \times 10^{-5} \text{ kg/s}$$

$$Q_{LPG} = 3.3 \times 10^{-5} \text{ kg/s} \times 46607 \text{ kJ/kg}$$

$$= 1.53803 \frac{\text{kJ}}{\text{s}} = 1538.03 \text{ J/s}$$

b) Energy loss through the wall, *Q_{wall}*

The calculation of *Q_{wall}* is conducted using equation (7). *Q_{wall}* is the energy loss to the wall. The area of the wall, therefore, is the total wall of the stove minus the wall area which was installed by the TEG module. In this work, the temperature of the whole wall is assumed to be the same due to the small area of the wall. The temperature of the wall surface (*T_s*) is the same as the temperature of the TEG hot side, as given in Table 2.

$$\begin{aligned} h_{in} A_1 (T_f - T_s) + \epsilon_f \sigma A_1 (T_f^4) \\ = h_o A_1 (T_s - T_a) + \epsilon \sigma A_1 (T_s^4 - T_a^4) \\ 10 \times 0.0209 (T_f - 446.397) \\ + 0.061x(5,67 \times 10^{-8}) \times 0.0209 (T_f^4) \\ = 100x 0.0209(446.39 - 305) \\ + 0.85 \times (5,67 \times 10^{-8})x 0.0209(446.397^4 - 305^4) \end{aligned}$$

$$T_f = 1229 \text{ K}$$

T_f is the temperature of the combustion flame at the steady condition. T_f is assumed to be the same during the stove operation with different cooling methods.

The loss of energy through the wall is:

$$\begin{aligned} Q_{\text{wall, in}} &= h_i A_1 (T_f - T_s) + \epsilon_f \sigma A_1 (T_f^4) \\ &= 10 \times 0.0209 (1233 - 446.39) \\ &\quad + 0.061 \times (5.67 \times 10^{-8}) \times 0.0209 (1229^4) \\ &= 321.44 \text{ J/s} \end{aligned}$$

$Q_{\text{wall, in}}$ is varied depending on the temperature of the wall surface (T_s).

c) The energy released by gas combustion, Q_{flame}

The calculation of the energy released by the combustion flame is conducted using equation (8).

$$Q_{\text{flame}} = \dot{m}_f C p_f (T_f - T_a)$$

The data used for the calculation is:

$$\begin{aligned} \dot{m}_{LPG} &= 3.3 \times 10^{-5} \text{ kg/s} \\ \frac{\dot{m}_a}{\dot{m}_{LPG}} &= \frac{\dot{m}_a}{3.3 \times 10^{-5}} = 15.67 \text{ [x]} \\ \dot{m}_a &= 15.67 \times (3.3 \times 10^{-5} \text{ kg/s}) = 5.148 \times 10^{-4} \text{ kg/s} \\ \dot{m}_f &= \dot{m}_{LPG} + \dot{m}_a = 3.3 \times 10^{-5} + 5.148 \times 10^{-4} = 5.48 \times 10^{-4} \text{ kg/s} \end{aligned}$$

The energy of the gas flame is calculated using equation (8):

$$\begin{aligned} Q_{\text{flame}} &= \dot{m}_f C p_f (T_f - T_a) \\ Q_{\text{flame}} &= 5.48 \times 10^{-4} \frac{\text{kg}}{\text{s}} \times 1.480 \text{ Kj/Kg.K} (1229 - 305) = \\ &= 0.749127 \text{ kJ/s} = 749.127 \text{ J/s} \end{aligned}$$

Q_{flame} is assumed to constant during the operation of the stove with different cooling methods.

d) Energy absorbed by TEG module, Q_{TEG}

The energy used by the TEG module is calculated using equation (12).

$$\begin{aligned} Q_{\text{TEG}} &= h_i A_2 (T_f - T_s) + \epsilon_f \sigma A_2 (T_f^4) \\ Q_{\text{TEG}} &= [10 \times 0.0064 (1229 - 446.39)] + \\ & [0.061 \times (5.67 \times 10^{-8}) \times 0.0064 (1229^4)] \\ Q_{\text{TEG}} &= 99.96 \text{ J/s} \end{aligned}$$

Q_{TEG} is varied depending on the temperature of the wall surface (T_s). Fig. 10 shows the energy absorbed by TEG for different cooling methods. The result indicates that the different cooling methods give significant effects on the energy absorbed by TEG. Compared to the energy supplied by the LPG gas, which produced 1,538.03 Watt, the application of a thermoelectric module can reduce the heat loss to the environment by absorbing the heat in the range of 6.5–6.6 %. The heat absorbed in the waterblock was higher than that absorbed by another system with air cooling. This is acceptable as the thermal conductivity of water inside the waterblock is lower than that of the metal heatsink. The temperature of the TEG cold side would also not exceed the boiling point of water.

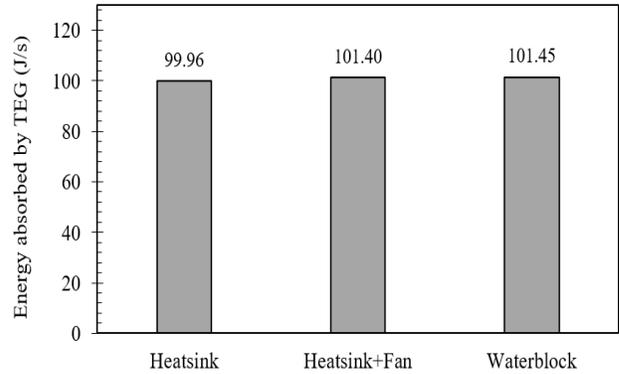


Fig. 10. The energy absorbed by TEG in the LPG stove with different cooling methods

B. Electrical performance

The power output of the TEG stove was measured to determine the energy absorbed by TEG, which converted into electrical power output. Fig. 11 shows the net power output of the TEG stove systems with different cooling methods. The result shows that the power output of the TEG system using different systems is in accordance with the temperature profile of the TEG temperature difference as described in Fig. 9. The power output of the TEG stove using waterblock is much higher than that of the system using heatsink+fan and heatsink. Table 4 gives the average power output obtained by measurement and calculation. The use of heatsink+fan and waterblock is still acceptable since the requirement of the additional power is 0.5 and 1 Watt, respectively.

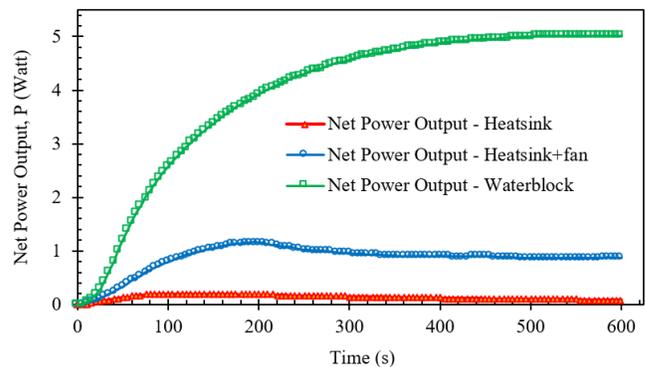


Fig. 11. Profile of power output of the LPG stove using heatsink, heatsink+fan, and waterblock as the cooling methods

Using the data given in Table 3, the calculation of the electrical performance of the TEG system can be done using equations (13)-(15). Fig. 12 shows the comparison of the result obtained by calculation and that obtained by measurement. The result shows that the power obtained by calculation is higher than that obtained by measurement. The electric current flowing through the TEG system circuit:

$$I = a \cdot \Delta T / (R_i + R_L) = \frac{0.054 \times 35.00}{5+10} = 0.126 \text{ A} \times 4 \text{ module} = 0.504 \text{ A}$$

The maximum power produced by TEG:

$$P_{max} = N \frac{\alpha^2 (T_H - T_c)^2}{4R_L} = 4 \frac{0.054^2 (446.40 - 411.39)^2}{4 \times 10} = 0.354 \text{ Watt}$$

The output voltage of TEG system with an external load of a DC lamp:

$$V_{cc} = \frac{P}{I} = \frac{0.357 \text{ Watt}}{0.504 \text{ A}} = 0.709 \text{ Volt}$$

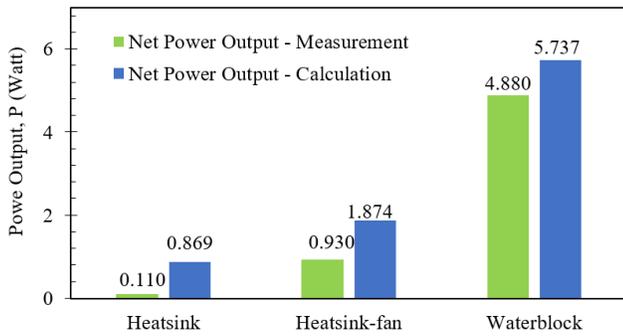


Fig. 12. The measured and calculated results of the power output of the LPG stove using heatsink, heatsink+fan, and waterblock as the cooling methods

V. CONCLUSIONS

The potential application of a thermoelectric LPG cooking stove for electrical power generation has been observed. The pan support of a commercial LPG cook stove was modified to adopt 4 TEG modules. Different cooling methods, including the heatsink, heatsink+fan, and waterblock, were used in the cold side of the TEG modules. Arduino was used as data acquisition to record the temperature measurement using thermocouples. The experiment was conducted to measure the temperature of the hot side and cold side of the TEG module and the power output of the thermoelectric LPG cooking stove. The result shows that the cooling method of heatsink, heatsink+fan, and waterblock sequentially increased the amount of energy absorbed by TEG modules, which consequently improved the net power output of the thermoelectric LPG cooking stove. The application of 4 TEG modules with the waterblock cooling method in the thermoelectric LPG stove produced 4.88 Watt energy. The generated power was measured when loaded using a DC lamp. The power output obtained by calculation was in good agreement with that obtained by the experiment. This work provides useful information to increase the effectiveness of the thermoelectric generator combined with different cooling methods in the LPG cooking stove.

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