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The Development of Waste Heat Energy Conversion Device to Generate Electricity through Thermoelectric Generator (TEG) Apply to LPG Cookstove

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Abstract

This research aims to develop the waste heat energy conversion device to generate electricity through a thermoelectric generator (TEG) which is called "CHEU. This device is applied to the LPG cookstove that serves as a waste heat source. The thermoelectric generator with 4 modules in series connection is used to convert heat energy to electricity. The present research shows a modification of the CHEU based on two concepts as follows: (1) re-design the structure for heat transfer improvement, and (2) select the high capability of TEG to support a high temperature from a heat source as a result of (1). In this study, the modified CHEU is called "MCHEU". A heat-load condition is set as the gas pressure of LPG, which varies in a range of 0.1 - 0.6 kg/cm^2, and the throttle valve is fixed approximately at 40% of a fully opened throttle, while the air entrainment is fully opened throttle. Also, the water-cooling system is used for heat dissipation. Base on the performance evaluation of MCHEU, the interesting results are drawn as follows: 1) the maximum temperature difference is on an average value of 278.5^{o}C at a maximum heat load condition, while a maximum voltage, current, and power are on an average value of 18.83 V, 5.67 A, and 107 W, respectively. 2) The temperature difference of MCHEU is higher than that of CHEU with an average value of 50%. 3) The output power obtained by MCHEU is higher than that of CHEU with an average value of 52% and takes less time about 40% for fully charging a battery (12V 7.5Ah). Nevertheless, MCHEU usage does not affect the thermal efficiency of a cookstove. 4) The efficiency of an energy conversion obtained by MCHEU is 20%, which is higher than that of CHEU about 2%.

Keywords: Thermoelectric; Energy Conversion; Waste Heat Energy

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1. Introduction

The domestic cooking stove is still necessarily used for cooking food that is the one-fourth factor for human life. Typically, there are many utilizations for using the cookstove namely households, food businesses or food industries, etc. The liquefied petroleum gas or LPG served as a fuel is used for many domestic cookstoves. According to the information on the energy consumption of LPG gas from 2010-2018 [1], [2], the LPG usage continuously increased. Now, it is the third-highest used fuel beside diesel and gasoline. As a result, the price of LPG increases yearly in Thailand. In general, the efficiency of LPG cookstove is just only in a range of 20–50% [3], and the rest is the heat loss into the surrounding. These energy losses are a high proportion when compared with the useful energy. Hence, it is an important problem for researchers who are interested in improving the efficiency of a gas stove with a friendly environment.

To obtain high efficiency and energy saving, the gas stove has been continuously developed by many researchers. Until now, the efficiency of the cooking stove is about 50–70% [4]-[6]. Unfortunately, the development of cookstove is limited by some reasons such as heat flow characteristics around the hot side and the cold side of the TEG. Therefore, the waste heat recovery (WHR) is additionally considered as a way to improve efficiency. The WHR is divided into two categories. Firstly, the waste heat recovery is used for increasing the efficiency of a furnace or gas stove [5], [6]. Secondly, the waste heat energy is converted to electricity through a device that is called the thermoelectric generator (TEG). D. Champier et al. [7] studied the thermoelectric power generation from biomass cookstoves. The results showed that the water-cooling system provided higher efficiency than air-cooled units. In addition, the biomass burner could produce approximately 7 W of power, of which 1 watt supplies power to electronic devices. The remainder was charged into the battery for a 2 W LED bulb of the lighting system, and 1 watt of a fan to feed the air into the furnace to increase combustion efficiency. R. Sakdanuphab and A. Sakulkalavek [8] studied the design of a waste heat recovery unit with a thermoelectric generator. The purpose of this paper was to study the influence of high temperature and the volume of water on the power generation and water temperature. The results showed that the high temperature was more significant than the volume of water. The efficiency of the WHR was higher than 80% due to the improvement of the thermal contact between the heat exchanger tube and the aluminum block. It also showed that the thermal efficiency was reduced by 5% when the WHR installed. A. Montecucco et al. [9] studied the use of 4 thermoelectric modules with Bi_2Te_3 material that were applied to the solid fuel furnace for charging batteries. The results showed that the heat power of 600 W could be converted to the electric power by 27 W for a 2-hour combustion period, and the thermoelectric efficiency was about 5 percent. M.J. Deasy et al. [10] studied electricity production from a biomass stove with a Bi_2Te_3 thermoelectric module using the Maximum Power Point Tracking (MPPT) control system and passive liquid cooling thermosyphon. The results showed that the maximum power output from a biomass stove integrated with a thermoelectric was approximately 5.8 W. The electricity was stable at the condition of 5 V via USB port for charging mobile phones, light bulbs, and an electrical energy storage device. Also, the result met the average power output that was higher than 4 W and this was enough to charge low-power electrical devices. S. Hemhiran and D. Tanpradit [11] studied the production of electricity from waste heat of the gas stove using a thermoelectric generator. The condition at gas pressure was in a range of 0.1 to 0.6 kg/cm^2 and the air entrainment was kept constant throughout the test. The results showed that the maximum power output was approximately 53.3 W at the gas pressure of 0.6 kg/cm^2, with the high and low temperature of the thermoelectric at 250.5^{o}C and 65.5^{o}C respectively. The efficiency of the TEG and the conversion efficiency were 5.3% and 18% respectively. In addition, when the electrical load was applied to a 12 V, 7 W of LED lamp at a gas pressure of 0.3 kg/cm^2, the temperature difference of thermoelectric was about 135^{o}C which could operate the LED lamp.

In the literature review above, the thermoelectric generator was mostly used for a biomass stove. However, so far there have been few studies of using the TEG for a household gas stove, which is mainly used for the food industry. Therefore, this research focuses on the improvement of a waste heat energy conversion device to generate electricity through the TEG applied to a household gas stove, which the KB-5 cookstove is used without any modification. In this study, the waste heat energy conversion device of S. Hemhiran and D. Tanpradit [11] is adopted. The structure of the device is modified by re-design for an expected rate of heat transfer enhancement to obtain effective conversion into electrical power. The present study not only investigates the characteristic of the modified CHEU (MCHEU) but also compares energy results with those obtained from the original CHEU.

2. Research Methodology

This section explains research methodology and the basic of thermoelectric, principle, mathematical model, materials and experimental setup and procedure, which are in the sub-section, are introduced as follows:

2.1 Basic of Thermoelectric Generator

The thermoelectric generator (TEG) device is a conversion device based on Seebeck's effect, which is composed of one or more thermoelectric couple. The simplest TEG consists of a thermocouple, comprising a pair of P-type and N-type thermoelements or legs connected electrically in series and thermally in parallel. The TEG device will generate DC electricity as long as there is a temperature gradient between its sides. When the temperature difference ($\Delta T = T_h - T_c$) across the TEG device increases, the more electrical output power will be generated as shown in **Fig. 1**.

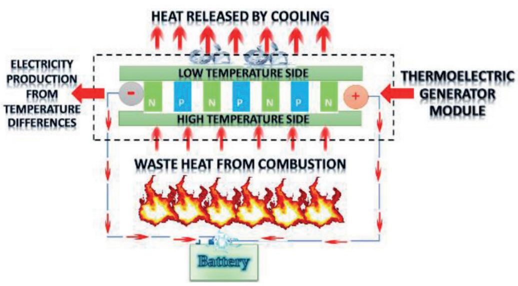


Fig. 1 Thermoelectric Principle

2.2 Mathematical Model

In this section, mathematical models are formed to analyze the thermal efficiency, heat transfer, a cooling system, an electrical power, and energy balance for the TEG gas stove application.

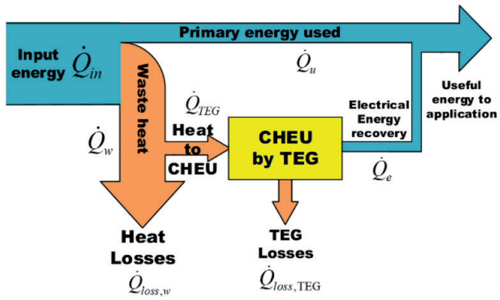


Fig. 2 Sankey diagram for TEG stove

2.2.1 Thermal Eefficiency of Cookstove

As shown in **Fig. 2**, the energy balance is started by equation (1),

$$\dot{Q}_{in} = \dot{Q}_{out} = \dot{Q}_u + \dot{Q}_w \quad (1)$$

where $\dot{Q}_{in}$ is the heat energy input that can be carried out by equation (2),

$$\dot{Q}_{in} = \dot{m}_f \times LHV \quad (2)$$

The primary useful heat ($\dot{Q}_u$) is useful energy rate defined as equation (3),

$$\dot{Q}_u = \dot{m}_{wt} c_{p,w}(\Delta T) + \dot{m}_{vp} h_{fg} \quad (3)$$

and is the primary loss of cooking stove. Then, the thermal efficiency of the gas stove can be calculated by equation (4),

$$\eta_{th} = \frac{\dot{m}_{wt} c_{p,w}(\Delta T) + \dot{m}_{vp} h_{fg}}{\dot{m}_f LHV} \quad (4)$$

Here, $\dot{m}_{wt}$ is the rate of water (kg/s), c_p is the heat capacity of water (kJ/kg°C), ΔT is the temperature change of water (°C), $\dot{m}_{wt}$ is the rate of stream (kg/s), h_{fg} is the latent heat of water (kJ/kg), $\dot{m}_f$

is the mass of LPG fuel (kg) and *LHV* is the low heating value (kJ/kg).

2.2.2 Heat Transfer of TEG

When η_{th} is known already, $\dot{Q}_w$ is defined by equation (5) and (6).

$$\dot{Q}_w = \dot{Q}_{in}(1-\eta_{th}) \tag{5}$$

$$\dot{Q}_w = \dot{Q}_{TEG} + \dot{Q}_{loss,w} \tag{6}$$

It is the waste heat from combustion. The term $\dot{Q}_{TEG}$ is the partial waste heat energy transferring to the TEG module, and $\dot{Q}_e$ is the electrical energy. The relation between $\dot{Q}_{TEG}$ and $\dot{Q}_e$ can be identified by equation (7), and it is equivalent to the heat transfer from heat source to heat sink, which can be expressed by equation (8) and is shown in **Fig. 3**.

$$\dot{Q}_{TEG} = \dot{Q}_e + \dot{Q}_{loss,TEG} \tag{7}$$

$$\dot{Q}_{TEG} = \frac{T_{\infty,1} - T_{\infty,5}}{\left[\frac{1}{h_1A_1} + \frac{\Delta X_A}{k_AA_2} + \frac{\Delta X_B}{k_BA_3} + \frac{\Delta X_C}{k_CA_4} + \frac{\Delta X_D}{k_DA_5} + \frac{1}{nh_5(A_b+\eta A_{fin})}\right]} \tag{8}$$

where k is the heat conduction coefficient on each material, h_1 and h_5 are the convection coefficient at positions 1 and 5, respectively, ΔX is the thickness of each material. The water-cooling flow through the low-temperature side of the TEG is used for this study because of the high heat transfer rate [7]-[11]. The rate of cooling $\dot{Q}_{cool}$ can be expressed by equation (9).

$$\dot{Q}_{cool} = \dot{m}_{wc}c_{p,w}(T_{wo} - T_{wi}) \tag{9}$$

where $\dot{m}_{wc}$ is the rate of water cooling, T_{wo} and T_{wi} are the outlet and inlet of water cooling, respectively.

2.2.3 Thermoelectric Capability

The property of the TEG is very important to identify the performances and characteristics of the TEG. Two parameters, i.e. 1) Seebeck's coefficient and 2) the equivalent thermal conductance (K), are used in this study as shown in equation (10) and (11), respectively.

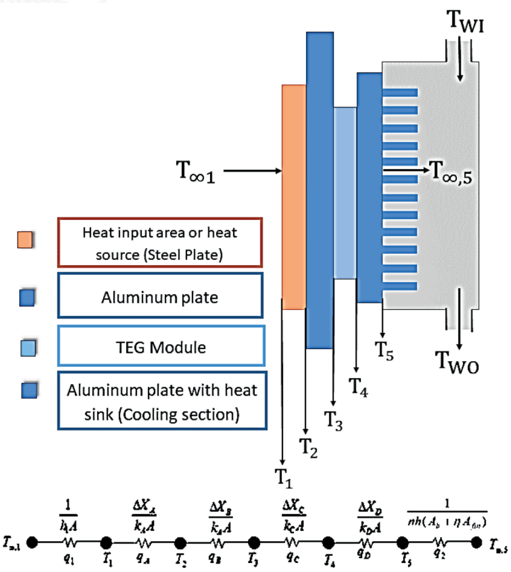


Fig. 3 Heat transfer model for analysis

$$S = \frac{V}{\Delta T} \tag{10}$$

$$K = \frac{2kAN}{l} \tag{11}$$

The heat flow from the exhaust is absorbed at the hot junction (Q_h), whereas the cold junction (Q_c) is released to the cooling system. They can be seen as equation (12) and (13), respectively. [12]

$$\dot{Q}_h = N(SIT_h + K(\Delta T) - 0.5I^2R) \quad (12)$$

$$\dot{Q}_c = N(SIT_c + K(\Delta T) + 0.5I^2R) \quad (13)$$

where A is the cross-sectional area of the each leg , V is the voltage output, ΔT is the temperature difference across the TEG, k is the conductivity of material, N is the amount of the TEG modules and l is the length of P-N type, I is the electric current, and R is the electric internal resistance. The efficiency of the TEG or thermoelectric conversion efficiency (η_{TEG})can be calculated by equation (14).

$$\eta_{TEG} = \frac{\dot{Q}_e}{Q_h} \quad (14)$$

The electric power can be calculated and is then compared with the measured result as equation (15) for validation.

$$\dot{Q}_e = VI = \dot{Q}_h - \dot{Q}_c \quad (15)$$

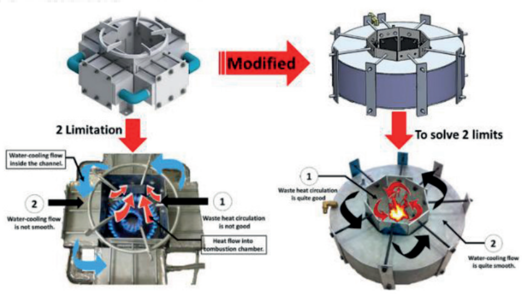
2.2.4 Energy Balance Equation

The heat balance equation of the system can be simplified by equation (1) – (7), as seen in equation (16), which the total heat loss of the system arises from the main heat loss $\dot{Q}_{loss,w}$ and the loss of the TEG module $\dot{Q}_{loss,TEG}$. Therefore, it reveals that the electrical power $\dot{Q}_e$ can be determined, if the term of $\dot{Q}_{in}$, $\dot{Q}_u$, $\dot{Q}_{loss,TEG}$, $\dot{Q}_{loss,w}$ are known by solvingin equation (2), (3), (6) and (15), respectively.

$$\dot{Q}_{in} = \dot{Q}_u + \dot{Q}_e + \dot{Q}_{loss,TEG} + \dot{Q}_{loss,w} \quad (16)$$

2.3 Material & Experimental Setup and Procedure

The concept design for the modified converting heat to electricity unit (MCHEU) is discussed in this part. Also, the materials used for structure, the water-cooling system, and the experimental setup and procedure are presented.



(a) (b)

Fig. 4 The problems of (a) original CHEU and (b) modified CHEU

2.3.1 Concept Design of MCHEU

In previous research [11], the converting heat to electricity unit (CHEU), as shown in **Fig. 4(a)**, could produce some electricity from the waste heat of a cookstove. However, the CHEU encounters some limitations of the heat flow characteristics around the hot side and the cold side of the TEG as also shown in **Fig. 4(a)**. Hence, the concept of re-design for the modified converting heat to electricity unit (MCHEU), as shown in **Fig. 4(b)**, is introduced to overcome these limitations. The basic idea for the structural design of the MCHEU is expected to be a circular shape because a circular shape is outstanding for the circulated heat flow, as depicted in **Fig. 5**. The area of the total internal surface of MCHEU is 0.0525 m^2 which is more than that of the CHEU about 2 times. The cross-sectional area of the water-cooling system is 90 mm × 90 mm, and there are two holes for a water inlet at the top and an outlet at the bottom. There are some baffles between the water inlet and outlet holes to ensure that the water can flow throughout all heat sinks. The 4 modules of the TEG are sequentially mounted on each plate that is a rectangular area with 60

Fig. 5 Design for MCHEU prototype

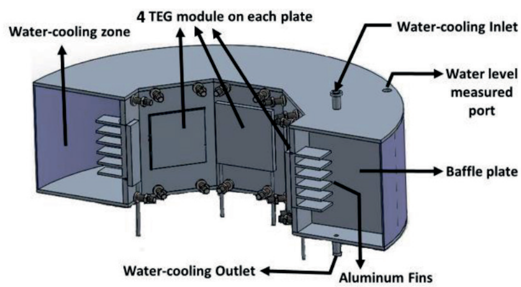


Fig. 6 MCHEU Structure

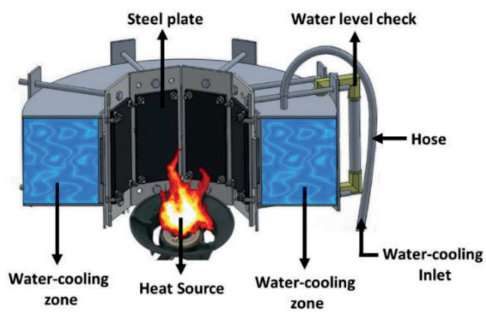


Fig. 7 MCHEU Structure & components

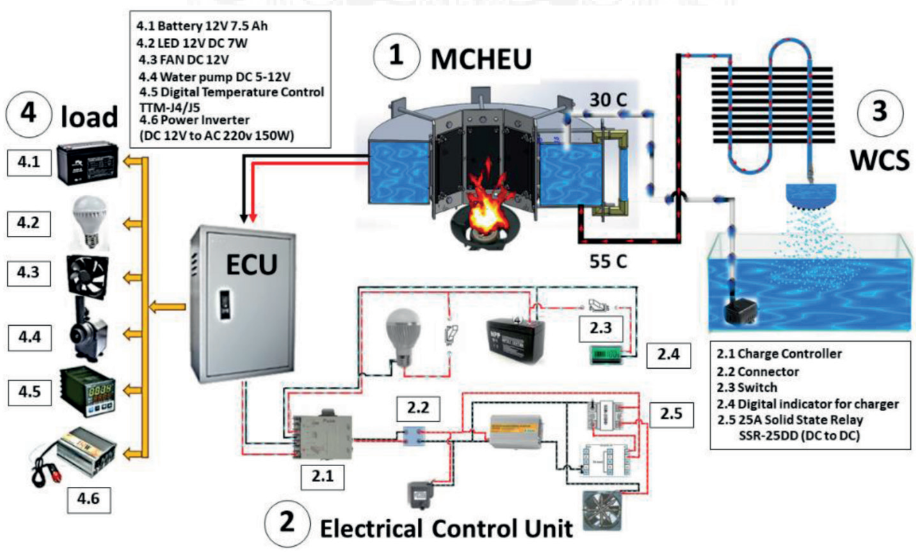


Fig. 8 Apparatus and components Installation

mm × 100 mm, as shown in **Fig. 6**. The 50 mm × 100 mm steel plate with a thickness of 5 mm is used for covering the TEG to prevent an overheated TEG at the hot section, as shown in **Fig. 7**. Otherwise, the TEG will be dramatically deteriorated.

2.3.2 Experimental Setup

A KB-5 LPG gas stove equipped with three main units is used to experiment. At first, The MCHEU works as a waste heat energy harvester. The 4 TEG modules, which are connected in the series because of promoting the current flow dominantly [12]-[13], are embedded inside the surface of MCHEU. The main parameters of the TEG are listed in **Table 1**. All TEG modules are attached to the k-type thermocouple for temperature measurement at hot and cold sides. The accuracy is +/- 2^{o}C in a range of 350 – 600^{o}C and is also combined to the data logger of the Yokogawa MV2040 series to monitor and record data. (Please check this sentence again)

Table 1 TEG's performance of CHEU and MCHEU

No	List of specification	Original CHEU	Modified CHEU
1	Thermoelectric generator (4 modules)	TEG-241-1.4-1.2 (7W 11.5V 1.25A 7Ω)	TEG-241-60B (19.7W 14.4V 2.9A 2.5Ω)
2	Material in module	Bi_2Te_3	Bi_2Te_3
3	Maximum temperature at hot side,(°C)	250	400
4	Seebeck's coefficient, (V/°C)	0.068	0.053
5	Heat conductivity, (W/m°C)	1.26	1.30
6	Internal resistance (Test), Ω	7	2.5
7	Size (WxLxH), mm	54.4x54.4x4	56x56x4

Secondly, all electrical wires on the TEG are connected to the digital multimeter of Kyoritsu model 1009 for measurement and are also combined with the electrical control unit (ECU). The ECU is composed of the electrical charge controller and the electric power distribution. The electricity distributes to the load via connectors such as a 12 V and 7.5 Ah battery, a 12 V and 7 W LED, a 12 V fan DC, a 12 V water pump DC, a digital temperature control TTM J4-J5 and a power inverter (12VDC to 220VAC 150W). Thirdly, instead of the air-cooling system, the water-cooling system (WCS) is used with MCHEU because it can provide higher heat transfer rates [7]-[11]. This system consists of a 23-liter tank, a 5-V water pump operating at 3.9 L/min, and a hose for water flow. All devices can be seen in **Fig. 8**.

2.3.3 Procedure

Firstly, the LPG fuel tank with a regulator is placed on the digital weight to measure fuel consumption during the test. The tank contains 23 liters of water that is combined with the small cooling tower. **Fig. 9** illustrates all equipment and devices that are installed for experiments. They must be precisely checked for availability, then switching on the ECU. Later, the 3 liters of water is supplied by a pump into the pot, which places onto the MCHEU. All data for the initial condition such as the water temperature in the tank (WCS) and weight of the LPG tank before the test are measured and recorded. Then, the regulator is adjusted to 0.1 kg/cm^2, while the throttle valve for primary airflow is fully opened by following the condition as listed in **Table 2**. The gas pressure is varied in the range of 0.1 – 0.6 kg/cm^2 that serves as a heat load because this condition can produce a high temperature under the TEG specification. During the water boiling, the temperature on both sides of the TEG and the electrical parameters are recorded by the data logger until it approaches steadily for 20 minutes. When the first condition is finished, it continues to the next condition according to **Table 2**.

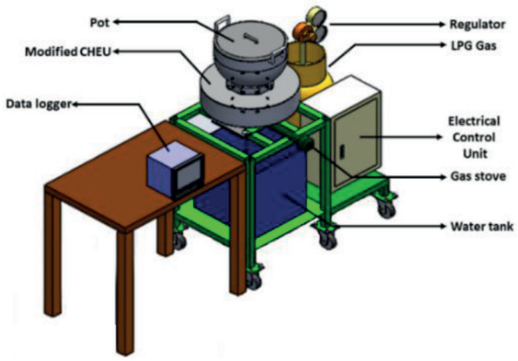


Fig. 9 Equipment installation

Table 2 The condition for TEG test

No	List	Conditions
1	LPG Gas stove	KB-5
2	Gas pressure (kg/cm2)	0.1 – 0.6
3	Position of valve for air combustion	Full throttle
4	Position of valve for fuel controlling	40% of full
5	Cooling system	Water-cooling
6	Water quantity (L)	3.0
7	Boiling time (min)	20

3. Results and Discussion

The temperature characteristics of the TEG and the electric voltage, current, and power are discussed. Also, the comparative study between the CHEU and MCHEU is investigated. **Fig. 10** shows clearly that the hot-side temperature of the TEG increases proportionally with the gas pressure because more fuel combustion causes the increase in the combustion temperature, while the cold side of the TEG is controlled by the water-cooling system. As a result, the temperature differences increase with the gas pressure in which the maximum temperature differences are 269.8^{o}C and 278.5^{o}C at 0.5 kg/cm^2 and 0.6 kg/cm^2, respectively. Because of the limitation of the TEG property, the temperature at the hot side of the TEG must be prevented by the steel plate to keep the temperature lower than 400^{o}C. Consequently, the temperature differences at the gas pressure of 0.5 kg/cm^2 and 0.6 kg/cm^2 are slightly different. **Figs. 11 and 12** show the average electric voltage and current outputs that are plotted against the temperature difference of the TEG at variant gas pressure. The results show that when the temperature difference increases, the electric voltage, and current output almost linearly increase [11], [12]. In fact, the Seebeck effect of the TEG reveals the constant of the Seebeck coefficient, which is shown by its slope of the result. This is approximately 0.0668 V/C to relate linearity between them, then temperature difference, and the electric output is almost linear.

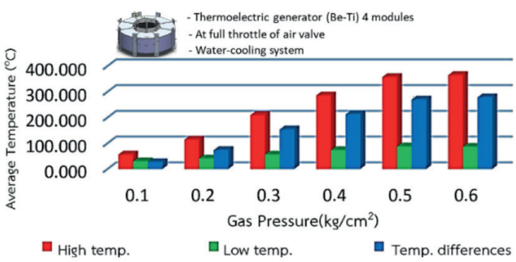


Fig. 10 Average temperature of TEG

Figs. 11 and 12 also indicate that the highest voltage output is 18.80 VDC at the maximum temperature difference of 278.50°C with 0.6 kg/cm^2 of the gas pressure, whereas the maximum current output is 5.70 A at the same condition. The effect from those results can be integrated by **Fig. 13**, which reveals the electric power.

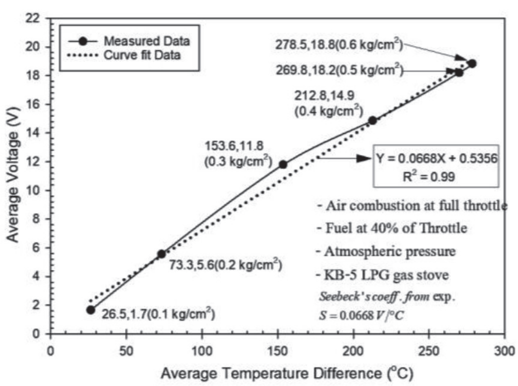


Fig. 11 Electric voltage of TEG

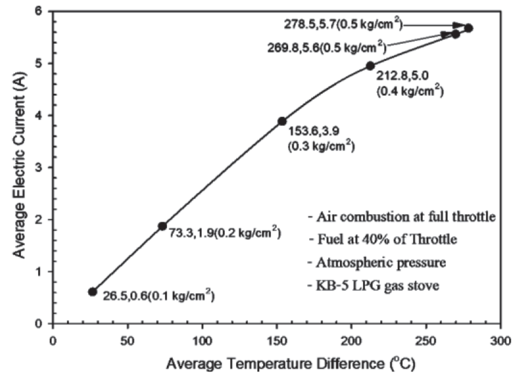


Fig. 12 Electric current of TEG

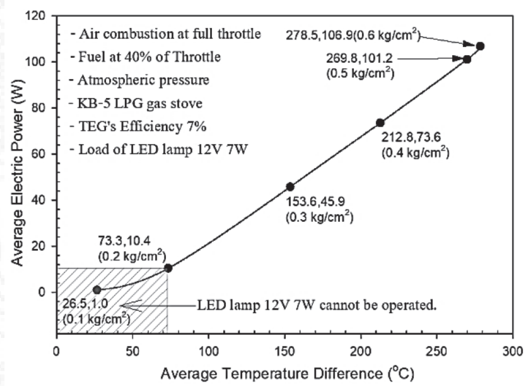


Fig. 13 Electric power of TEG

It shows the maximum power is approximately 106.90 W. This result corresponds to the result reported by [11] and [14]. Furthermore, a 12 V and 7 W LED lamp can be operated over 70°C of the temperature difference [12]. In the present study, the TEG provides a 7% average efficiency, approximately which also agrees with the efficiency reported by [11], [12].

Fig. 14 shows the validation of the computed TEG's output power which is done by comparing it with the measurement and calculation. Clearly, the trend of the measured result agrees with the calculated result. However, the calculated result is lower than the measured result, on an average value, about 20%. This error occurs due to the inaccuracy of a measured Seebeck coefficient (0.0668 V/°C). In addition, the Seebeck coefficient is further studied in the case of 0.85, which is very close to the experimental result.

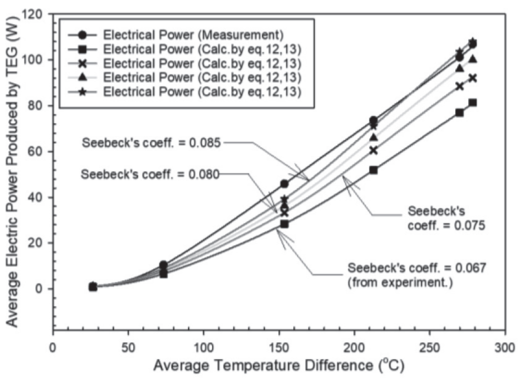


Fig. 14 Validation of power output.

Fig. 15 presents the thermal efficiency of the gas stove with and without MCHEU. One can see that the thermal efficiency with and without MCHEU is 27.5% and 27.8% on average, respectively. It is insignificantly different,

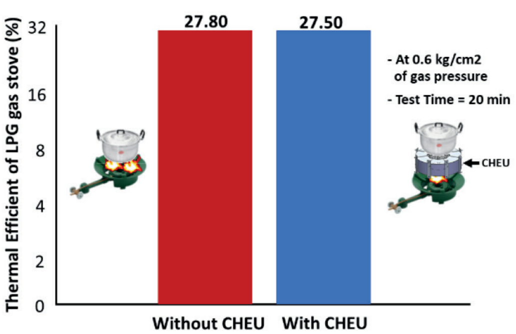


Fig. 15 Thermal efficiency of gas stove

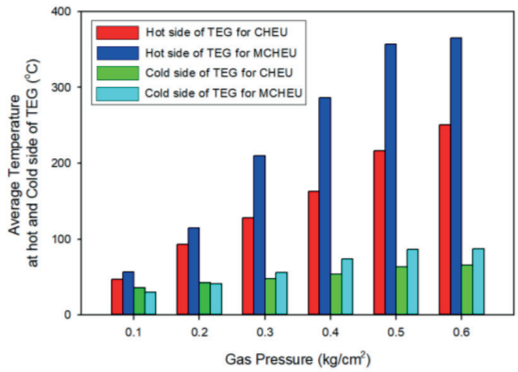


Fig. 16 Temperature at hot and cold side

only0.3% [8] and [11]. Thus, it indicates that the cookstove can be integrated by MCHEU without reducing efficiency.

The comparative results between MCHEU and CHEU can be seen in **Figs. 16 - 21**. **Fig. 16** shows the hot and cold side temperatures of the TEG with CHEU and MCHEU against the gas pressure. Obviously, the temperature at the hot side of MCHEU is much higher than that of CHEU. This may be explained by the fact that the MCHEU is improved by re-designing the structure for a turbulent flow enhancement of the exhaust gas, while the control of the temperature at the cold side is attempted by the water-cooling system. The results indicate that the highest temperature at the hot side of MCHEU and CHEU is 364.71°C and 250.50°C, respectively, at the maximum heat load. Next, **Figs. 17, 18, and 19** compare the results of the open-circuit voltage, the electric current (Short-circuit), and the output power with the CHEU and the MCHEU against with the temperature difference.

They show that at the highest heat load, MCHEU can provide the maximum of the electric voltage (Open-circuit), the current (Short-circuit), and the power output of are 18.8V, 5.7A, and 107W, respectively. Meanwhile, 38.8V, 1.4A, and 58.1W are given by CHEU. **Fig. 17** also indicates that the open-circuit voltage of CHEU is higher than that of MCHEU approximately 2 times. This is because the Seebeck's coefficient of the CHEU is higher. In contrast, the current of MCHEU is higher than that of CHEU about 4 times, as seen in **Fig. 18**. This is because of the high capability of TEG's specification.

However, although the voltage output of MCHEU is lower, the power output of MCHEU is higher about 2 times, as shown in **Fig. 19**. Namely, the output power obtained by MCHEU is higher than that by CHEU approximately 50%. This is because the temperature difference of the TEG is increased by a modified structure to improve the heat transfer. Moreover, a high capability of the TEG is used to withstand the high temperature from the exhaust gas. Also, a LED lamp (12VDC 7W) can be operated by both CHEU and MCHEU at the same condition but MCHEU can produce more power than CHEU.

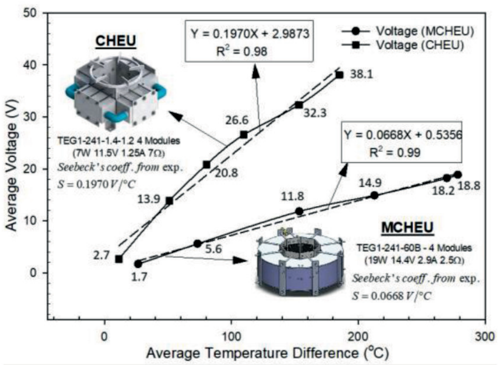


Fig. 17 Voltage (Open Circuit) of TEG

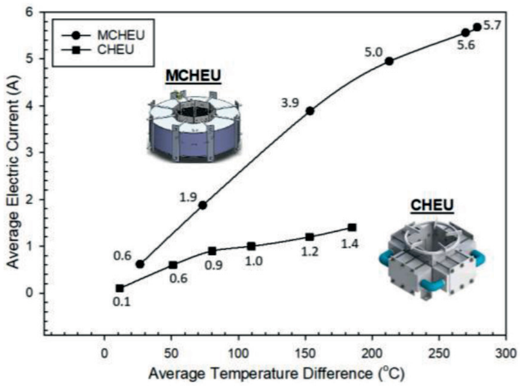


Fig. 18 Current (Short Circuit) of TEG

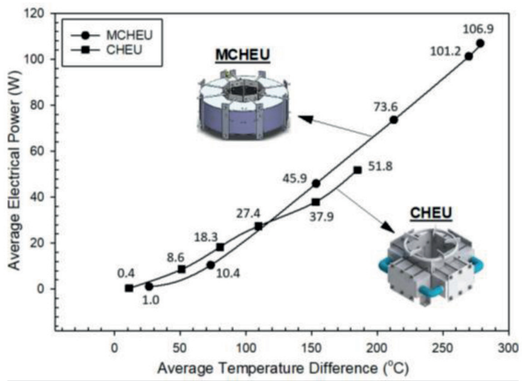


Fig. 19 Electric power of TEG

Fig. 20 presents the battery-charging time between CHEU and MCHEU. The result shows that the battery (12V 7.5Ah) is charged by MCHEU and CHEU at the rate of 0.37 V/hr and 0.16 V/hr, respectively. Hence, the charging time of MCHEU and CHEU can be estimated for 4.5 hours and 7.8 hours at a full-charged battery. It means that the battery can be charged up faster by MCHEU. As a result, the electric current flowing from MCHEU into the battery increases with an increasing duty cycle as the duty cycle is further increased [15].

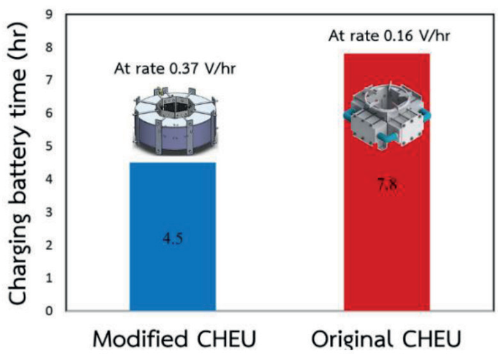


Fig. 20 Battery charging time

To complete the comparison, the energy-saving provided by the gas stove with CHEU and MCHEU is presented in **Fig. 21**.

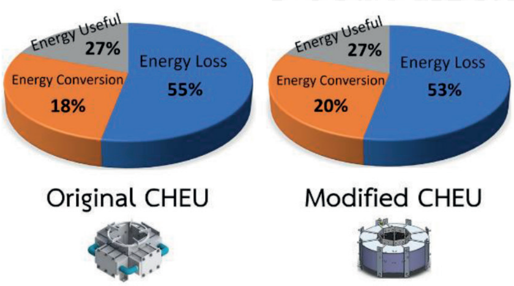


Fig. 21 Energy saving aspect

The pie charts are divided into three parts, namely, the useful energy, the energy conversion (Electricity), and the energy loss. It is clear that the gas stove with MCHEU and CHEU can recovery the electricity by approximately 20% and 18%, respectively. Also, energy loss decreases by 2%. This means that the waste heat can be converted to the electricity increasingly by the gas cooking stove with MCHEU. Also, the gas cooking stove with MCHEU can operate with being more friendly environment. and the use of MCHEU does not affect the thermal efficiency of the gas stove.

4. Conclusion and Suggestion

This work emphasizes the importance of developing the waste heat energy conversion device to generate some electricity through a TEG. Through analysis and discussion, the performances of the MCHEU are investigated and compared with those of the original CHEU as concluded in **Table 3**.

Table 3 Comparison between CHEU and MCHEU

No	List for comparison	Original CHEU results	Modified CHEU result	Differences
1	Temperature differences of TEG (Range)	11.2 – 185 °C	26.5 – 278.5 °C	↑ 15.3 – 93.5 °C
2	Maximum Power produced by TEG	51.79 W	107 W	↑ 55.13 W
3	Charging battery time at full (12 V 7.5 Ah of battery capacity)	7.8 hr (at rate 0.16 V/h)	4.5 hr (at rate 0.37 V/h)	↓ 3.3 hr
4	Thermal efficiency of gas stove	27.8 %	27.5 %	↓ 0.3 %
5	TEG efficiency	5.3 %	7 %	↑ 1.7 %
6	Conversion efficiency heat to electricity	18 %	20 %	↑ 2 %

The interesting results are summarized as follows:

1) The maximum temperature difference of MCHEU is on an average value of 278.5°C at a maximum heat load condition, thereby obtaining the maximum voltage, current, and power are 18.83 V, 5.67 A, and 107 W respectively.

2) On average, the temperature difference of MCHEU is 50% higher

than that of CHEU. 3) The output power obtained by MCHEU is higher than that of CHEU with an average value of 52%, and takes less time about 40% for fully-charging a battery (12 V, 7.5 Ah). Nevertheless, MCHEU usage does not affect the thermal efficiency of the gas cooking stove. 4) The efficiency of an energy conversion obtained by MCHEU is 20%, which is higher than those of CHEU about 2%.

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