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Improving the performance of a gas stove-powered thermoelectric generator (GSPTG) by adding a fin hot side heat exchanger (F-HHX)

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Abstract

Utilizing waste heat into electrical energy from conventional gas stoves is possible by applying a thermoelectric generator (TEG). This research conducted a more in-depth study regarding the use of a Fin Hot Side Heat Exchanger (F-HHX) of a Gas Stove Powered Thermoelectric Generator (GSPTG) to improve the produced power output from TEG. The three models of F-HHX used in this research are short fin, long fin, and tilted fin. Four TEG are connected in a series circuit and placed on the gas stove. Measurements were made on temperature and electrical output from TEG. The energy balance calculation was carried out to determine the efficiency of GSPTG. The research results show that using F-HHX will affect the energy balance and electrical output from GSPTG. The tilted fin type absorbs the most heat energy from a heat source at 94.112 J/s. The results of measuring the power output of the TEG module when the F-HHX tilted fin model is applied produce the highest power output at 3.369 Watts if compared with the other fin. Using the F-HHX tilted fin model indicates that it is more effective as a GPSTG hot side heat exchanger because it absorbs more heat and produces a power output.

Keywords

GSPTG, F-HHX, TEG module

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Introduction

The success of the Indonesian government in carrying out a program to convert the use of oil-fueled stoves to LPG gas-fueled stoves in 2007 is likely successful [1]. However, it should be noted that the efficiency of the heat energy used for cooking on a conventional LPG gas stove is only around 66.27% or 1.784 KW of the total energy supplied to the gas stove. At the same time, the rest is wasted into the environment in the form of heat energy and combustion gases [2]. Let us look further into the mechanism of the LPG gas stove system. There is the potential to utilize the heat wasted into the environment from the combustion of LPG gas stoves into other, more useful energy. Generating electrical energy by utilizing waste heat energy has attracted much attention among researchers for at least the last three decades using thermoelectric generator (TEG) modules [3]. A *thermoelectric generator* is a technology that directly converts the temperature difference on both sides of the TEG surface into electrical energy through the Seebeck effect and the semiconductor material components that make up the TEG. However, the TEG has a fairly low conversion efficiency, namely around 5-8% [4][5]. The redevelopment of thermoelectric has started in the last two decades [6]. The material commonly used as a TEG module material is bismuth telleruide (Bi_2Te_3) [4]. The basic principles of thermoelectric generators can be seen in Figure 1.

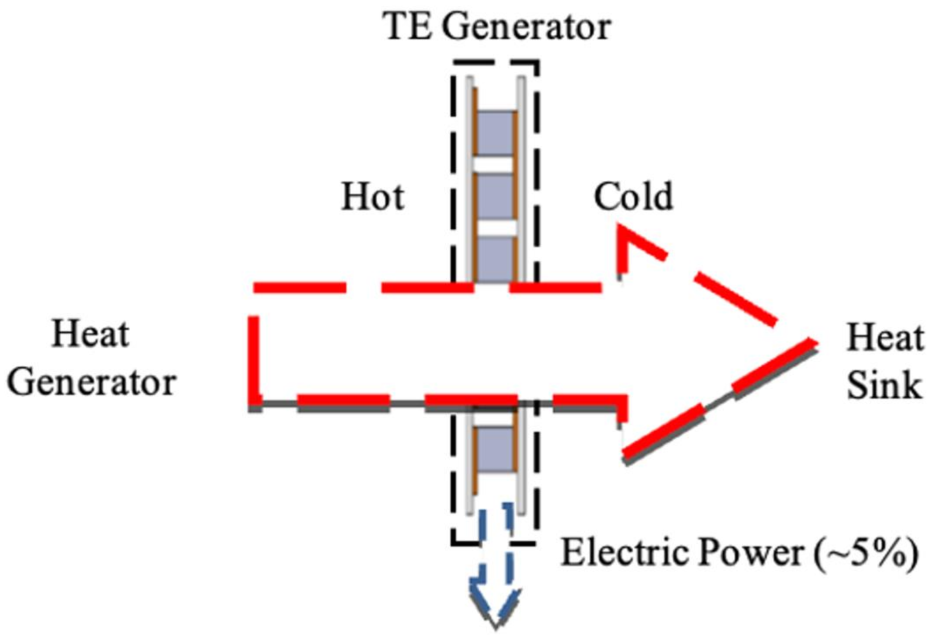

Figure 1. Basic principles of TEG [7]

Generally, there are three main components in applying a TEG module utilizing wasted heat energy: Hot-side Heat Exchanger, thermoelectric module, and Cold-side Heat Exchanger. To maximize TEG's performance, three components must be considered [8], [9]. Many types of HHX are commonly used in waste heat utilization using TEG modules, including metal foam [10][11] and finned plates [12][13].

When TEG is applied to a gas stove, it is important to know that the energy balance on the gas stove follows the first law of thermodynamics [14]. However, because the heating value of the air entering the stove is too small, it can be ignored, and there is combustion efficiency in a gas stove [15]. So, the energy balance contained in the gas stove can follow the equation below:

$$\mu c.QLPG = Qflame + Qwall + QHHX \quad (1)$$

$$Q_{HHX} = (A_{unfin}.h_i.(T_f - T_{fin}) + \mu_{fin}.A_{fin}.h_i.(T_f - T_{fin})) + (\varepsilon_f.\sigma.A_{fin}.T_f{}^4) \quad (2)$$

Where Q_{HHX} is the heat energy absorbed by F-HHX, while h_i is represents the heat transfer coefficient in the gas stove, A_{fin} is the total area of the fins, T_f is the flame temperature at constant pressure while T_{fin} is fin temperature, σ is Stefmant Boltzmann's determination and ε_f is the gas emissivity.

Figure 2 shows the electrical circuit of the TEG system when given an external load as a DC lamp. This loading aims to find the maximum power the TEG module transfers if more than 1 module is used. Calculation of TEG performance in electrical circuits with light loads is carried out as follows [16]:

Voltage Open Circuit from TEG:

$$V_{oc} = a(T_H - T_c) \qquad (3)$$

Electrical current from TEG:

$$I = a.\Delta T/(R_i + R_L) = V_{oc}/2R_i \qquad (4)$$

Net power output from TEG:

$$P_{max} = N\, I^2 R_L = N\, \frac{a^2(T_H - T_c)^2}{4R_L} \qquad (5)$$

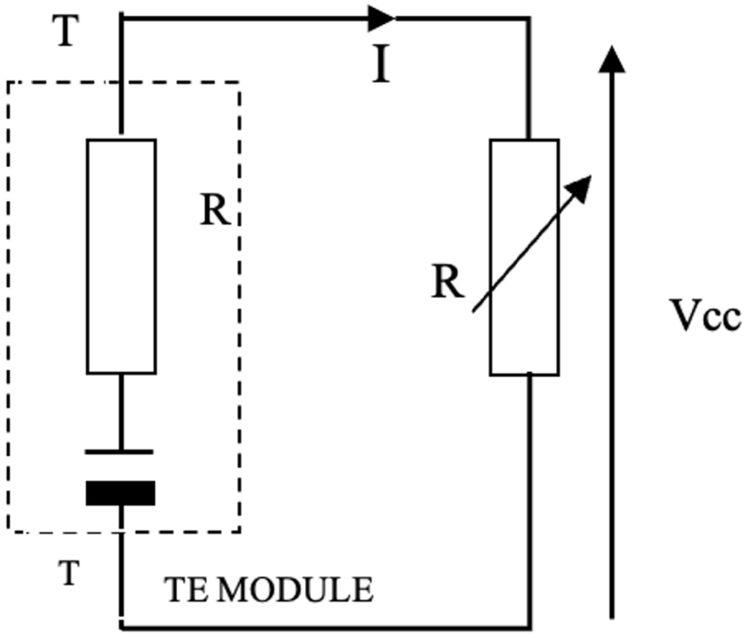

Figure 2. Electrical circuit of TEG

Based on studies that have been carried out, it is known that the electrical energy output and maximum performance of the TEG system have several influencing factors, including HHX width, HHX thickness, and HHX fin shape [17]. So, there is a need for deeper identification regarding the use of waste heat in LPG gas stoves by varying the HHX with small fins, long fins, and tilted fins. This research is important to obtain data regarding the type of HHX capable of producing the most optimal power from the TEG module.

Method

Figure 3 shows a research scheme for utilizing waste heat from a gas stove. From this scheme, there are 4 TEG modules arranged in series. The TEG module used is of the SP1848-27145 SA type [18–20]. The TEG cooling system of cold surfaces utilizes circulating water with a water volume of 4 liters. Data was collected using an Arduino data logger as a temperature data acquisition tool. Meanwhile, the electrical energy output from the TEG is measured when the module is loaded with a DC light to find the net power output from the TEG [16]. The electrical output data collection uses a USB multimeter to acquire data. Apart from that, the electrical output data collection aims to determine the performance of the TEG installed on the gas stove in the form of voltage, current, and power produced by each variation of the F-HHX shape. So that the performance of the TEG installed on the gas stove can be known through the data analysis process.

The F-HHX variations and the position of temperature data collection in this research can be seen in Figure 4. Temperature data collection uses a type K thermocouple combined with an MAX6675 temperature sensor and Arduino Mega. Temperature data collection is carried out on the surface temperature of the hot side of TEG ($T._{Hot}$) and the temperature of the cold side of TEG ($T._{Cold}$).

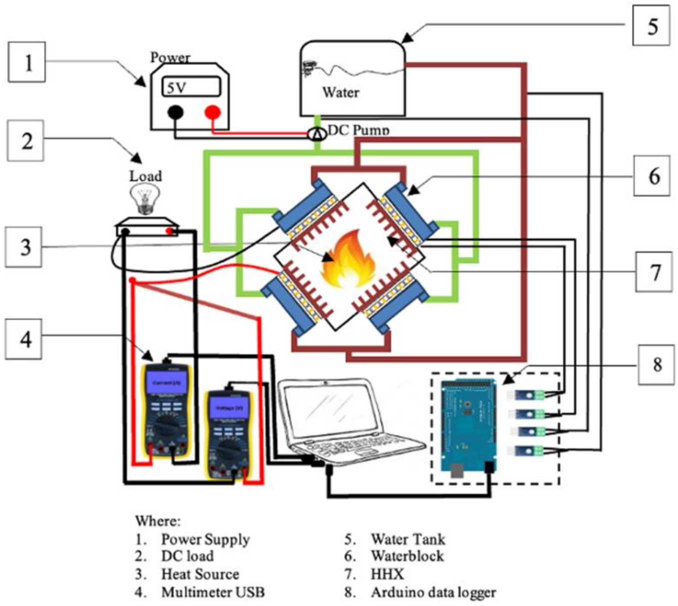

Figure 3. Research schematic for utilizing waste heat on LPG gas stoves using the TEG module

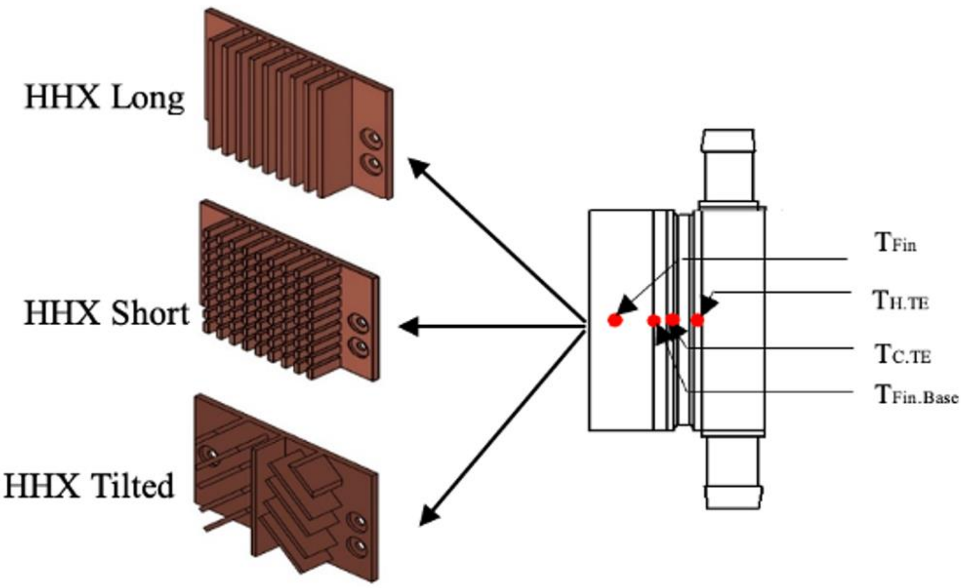

Figure 4. F-HHX variations and the position of temperature data collection

Result and discussion

Temperature surface of TEG

The results of data collection on the F-HHX short fin, long fin, and tilted fin type are shown in Figure 5. The components measured are the temperature on the surface of the hot side of the TEG ($T._{Hot}$) and the temperature of the cold side of the TEG ($T._{Cold}$). The graph shows that the use of F-HHX with the tilted fin form was recorded as having the highest temperature. When using the F-HHX long fin, the trend of temperature changes tends to be unstable; this is possible because there is quite high air circulation around the gas stove, which causes the heat source to be unstable. Meanwhile, the F-HHX short fin produces the lowest temperature on the TEG hot surface. This indicates that the F-HHX tilted fin is more effective in transferring heat energy from the heat source. On the other hand, using F-HHX does not affect temperature changes on the cold surface of the TEG.

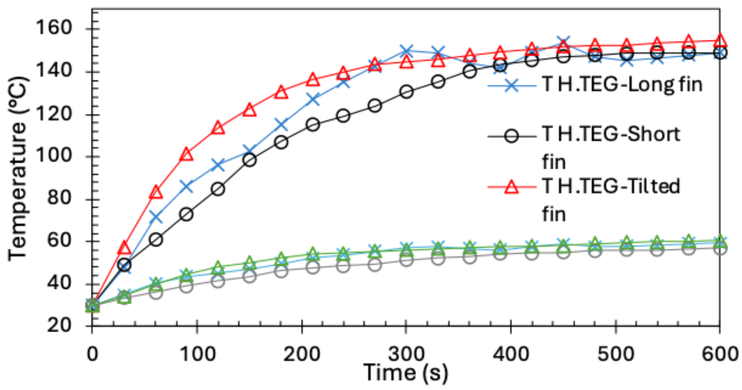

Figure 5. Temperature surface of TEG when using F-HHX short fin, long fin dan tilted fin.

Energy absorbed by F-HHX

The results of calculating heat energy absorbed by F-HHX on GSPTG can be seen in Table 1. The table of results of the energy balance calculation shows that variations in F-HHX will affect the energy balance that occurs on GSPTG. Based on calculations according to equation (2), the use of the tilted fin F-HHX can absorb the most heat energy from heat sources, namely 94,112 J/s, while the use of long fin and short fin F-HHX absorbs less heat energy from heat sources. This indicates that a tilted fin is more effective as a heat exchanger component in GSPTG.

Table 1. Heat absorbed by F-HHX calculation pada GSPTG

No	F-HHX Model	T.Wall (K)	T.Ambient (K)	Heat absorbed by F-HHX (QHHX, J/s)
1	HHX Short fin	429.58	305	87.406
2	HHX Long fin	433.44	305	90.333
3	HHX Tilted fin	438.68	305	94.112

GSPTG performance

Figure 6 shows the effect of F-HHX variations on the net power output produced by GSPTG. The net power output from GSPTG is obtained from the temperature difference in the TEG, which produces output in the form of voltage and current for each F-HHX variations. Meanwhile, net power output is the product of current and voltage.

Figure 7 compares performance results in the form of power produced by GSPTG between calculations using the formulation and experimental measurement results. In the long fin variation, the electrical power produced based on measurement results is 2,109 watts, while the calculation results show that the power is 5,727 watts. Furthermore, the power produced by the F-HHX short fin from the results of measurements and calculations is 2,008 watts and 5,911 watts, respectively. Of the three variations of the F-HHX fin used, the F-HHX tilted fin produces the highest power compared to the others. The measurement results and calculation of net power output from GSPTG show that the F-HHX tilted fin is 3,369 and 6,035 watts, respectively. This is because the most optimal heat transfer rate occurs in the tilted fin variation. Apart from that, the difference between measurement results and calculations on GSPTG performance in the form of power is possible because of the heat loss that occurs during the experiment. In contrast, during the calculation, the heat loss is ignored.

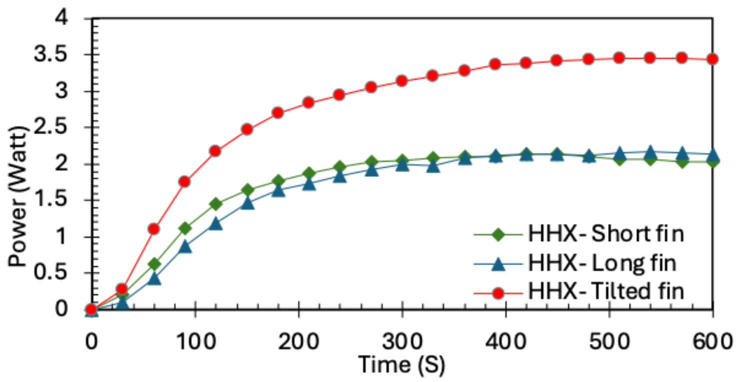

Figure 6. Net power output from GSPTG when using F-HHX type short fin, long fin and tilted fin

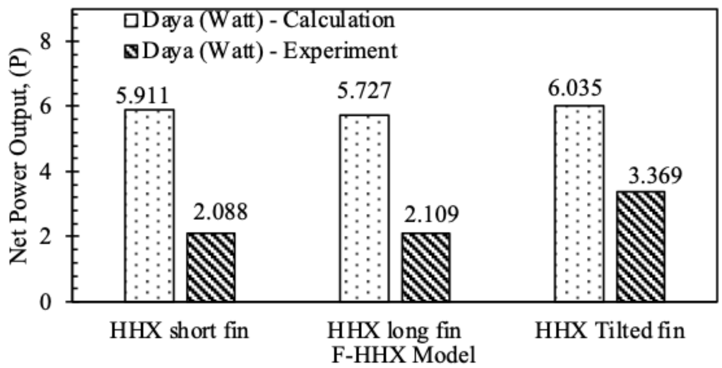

Figure 7. Net power output from GSPTG by experiment and calculation

Conclusion

Based on the analysis and calculations in this research, it can be concluded that F-HHX influences the energy balance and electrical power produced by GPSTG. The F-HHX tilted fin model absorbs the most heat energy from heat sources, namely 94,112 J/s. The results of measurements and calculations of output in the form of power from GPSTG using the F-HHX tilted fin model also obtained the highest value compared to the long and small fin variations, where the results of measurements and calculations obtained values of 3,369 Watts and 6,035 Watts, respectively. This indicates that the tilted fin is more effective as a heat exchange component on the hot side of the TEG.

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