Energy Harvesting from the Waste Heat of an Electrical Oven via Thermoelectric Generator

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Abstract. This paper presents an attempt to generate the electricity by recovering the waste heat of an electrical oven. An experimental work has been done to investigate the electricity production by using a thermoelectric generator (TEG). The performance characterization of TEG was experimentally investigated in an open circuit mode by connecting the multimeter directly to the TEG and in a closed circuit mode by connecting different load to the TEG. The key results showed that it is possible to generate up to 1 V and 30 mW in the open circuit condition, while the TEG could generate a 0.5 V and 25 mW in the closed circuit conditions when the maximum temperature differences across the TEG is about 20 °C. The power output could be increased by using more than one TEG module. This power could be used for charging a cell phone or light emitting diodes LEDs during cooking.

KEYWORDS: Waste heat, heat recovery, thermoelectric generator, electricity generation.

1. Introduction
The major source of electricity is generated through stations based on burring of the fossil fuels, which pollute the environment. Therefore, finding new sources of energy is important to overcome this problem. Renewable energy is considered as a reliable source of energy because of many reasons such as environment-friendly and unlimited source of energy.

Solar energy is one type of renewable energy that converts the sun light into electricity by using photovoltaic.

Thermoelectric generator is made from semiconductors N-type and P-type which is able to convert the waste heat into electricity using the electron as a working fluid by Seebeck effect [1]. Harvesting solar energy by thermoelectric generator was studied by many researchers [2][3][4][5] moreover, the use of biomass cooker stove as a source of heat for thermoelectric was investigated by [6][7]. The recovery of waste heat that dissipated to the environment was studied by using two stroke petrol engine and TEG [8]. An attempt to recharge a battery in a compression ignition engine has been done by experimental and theoretical work [9].

A waste heat recovery system based on a thermoelectric generator was designed by Demir and Dincer [10]. The system was integrated with the exhaust manifold of the automobile to recover the waste heat. Three TEG modules were used in the study. The maximum generated power from the waste heat was 158 W. The energy conversion efficiency was calculated based on the heat transfer rate from the hot side to the thermoelectric generators and the generated power.

There are many ways to harvest the waste heat at home [11][12][13]. However, integrating TEG with home electrical oven has not investigated yet.

The objective of this study is to investigate experimentally the electricity generation by TEG using the waste heat from electric oven. This electricity can be used to charge a battery of a cell phone or to power LEDs inside a house.
2. Experimental setup

A schematic diagram and actual photograph of the experimental setup is shown in figure 1. Two K-type thermocouples were used to measure the temperature of the hot side (TH) and the cold side (TC) of thermoelectric. The top thermocouple was attached to the surface of the oven by drilling a hole inside a copper plate to measure the hot side temperature. The cold side temperature was measured by using another thermocouple connected to the heat sink.

![Diagram](image)

**Figure 1.** Shows a schematic diagram (a), and actual photograph of the experimental (b).

A thin uniform layer of heat sink compound with a thermal conductivity of 2.9 W/m.K was applied between the oven and the thermoelectric also, between the cold side and the thermoelectric. A thermoelectric device (40 mm x 40 mm geometry and 256 legs) has been used during the experimental setup.

The thermoelectric generator is able to convert the thermal energy into electrical energy directly which is an alternative method to produce potential energy. The efficiency of thermoelectric converters in general, depends on the material and design aspects such as the number of legs and the lengths [2]. Also, the heat transfer conditions have a significant influence on power output generation and the efficiency of TEG. It is worth to mention that the power output in this work was calculated using the following formula which is usually used to calculate the power output in open circuit mode

\[ P = \frac{v^2}{4R} \]  

where \( v \) is open circuit voltage and \( R \) is the internal resistance of the TEG device. The internal resistance of TEG could be obtained by connecting different loads to the TEG, and then the value of the load at the maximum power output represents the internal resistance of the TEG.

The focus of this work is developing tools for the evaluation of thermoelectric power generation from the waste heat of an electrical oven. The power generated from this rig could be used for charging cell phone or other uses.
3. Results and Discussion

The oven was switched on for twenty minutes using both the upper and lower heater for the maximum temperature. The electrical oven was consumed electrical power \( Q_p \) approximately 686.4 W, which was calculated by multiplying the voltage by the current. First, the thermoelectric generator characterized using the open circuit method i.e without connecting load to the external circuit and the results are shown in figure 2. It can be shown in figure 2.a, the increase in the hot side temperature \( T_H \), cold side temperature \( T_C \) and the difference between them for the TEG with time. It is clear that both \( T_H \) and \( T_C \) are increasing with the time mainly due to transfer the heat from rear surface of the oven to the hot side of TEG then to the \( T_C \) via TEG.

The temperature difference across TEG causes generation of electricity by Seebeck effect as we can see in figure 2.b and the generated voltage is increased by increasing the temperature difference between them. Figure 2.c showed the open circuit voltage and the power output as a function of hot side temperature. Both of them were increased with increasing the hot side temperature due to increase in the temperature difference between the hot side (electrical oven) and the cold side temperate (heat sink).

After that, the load was connected to the TEG and the results are shown in figure 3. Figure 3.a shows the voltage generated by connecting difference resistance to the circuit. It can be seen that, the TEG was characterised at constant temperature difference when the electrical oven reached to the steady state condition where the \( T_C \) and \( T_H \) about 87 °C and 101°C respectively. The power output was calculated by multiplying the voltage by the current and the results are demonstrated in figure 3.b and 3.c. This experiment showed that the waste heat from oven can be used to generate useful DC voltage and power, which may be used to charge cell phone or power DC light during the night.
Figure 2. Shows the characterization of thermoelectric generator in open circuit mode, a. temperature Vs time, b. voltage and power Vs time and c. voltage and power Vs hot side temperature.
Figure 3. Shows the characterization of thermoelectric generator in closed circuit mode, a. voltage Vs load, b. power output Vs load and c. power output and current Vs voltage.
4. Conclusions

The thermoelectric generator is successfully integrated between the electrical oven and the heat sink which is capable of producing a DC electrical power from an electrical oven. It has been shown that the thermoelectric generator is producing more than 1 volt in open circuit mode and 0.5 volt in closed circuit condition during 20 minutes of the operation of the electrical oven. The generated energy can be store in a battery.

The study shows the availability and possibility of recovering the waste heat from electrical oven. Future work is investigating of; more than one TEG modules, active heat sink and charging portable cell phone charger.

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