Experimental Investigation on Thermoelectric Generator for Battery- Charger Based Oven

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Abstract – *In this paper, we demonstrate how electrical energy can be harvested from the heat waste of an electric kitchen oven, using a thermoelectric generator (TEG) module that is embedded inside the oven. The setup of the experiment was investigated in a closed-circuit, where the temperature was raised from room temperature to a temperature of 150°C in 60 min. The setup consists of a kitchen oven with a custom-made aluminum heatsink, and a built-in water-cooling tank attached to the TEG module. The maximum output voltage generated was measured to be around 1.87V in a single TEG module, where the measured gradient of TEG was around 0.0337V/°C. The harvested voltage was then used to fully charge an 'AA' size lithium battery within 110 mins. The battery was then used to power an LED torch light with power rating of 3W.*

Keywords: *Energy harvesting; thermoelectric generator (TEG); heat waste;*

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I. Introduction

The successful landing of the Apollo 13 spacecraft on the moon in the 70's marks the beginning of the new era of renewable energy, such as solar PV, geothermal, solar hot water, biomass & bio fuel, small wind turbine, solar space heating and combine heat & power energy [1]-[7], to name a few. The main driving force behind renewable energy is to find a substitute to the traditional way of generation of energy, which is by burning fossil fuel.

Though this had served humanity well in the last decades, but it is clear now that this method of energy generation is extremely polluting and harmful to the environment. Other form of renewable energy, like hydroelectric also cause major environmental impact, from deforestation for the purpose of building the dams for the generation of electricity.

As people are more aware of the environmental issues associated with the way we generate energy, more R&D efforts have been put into renewable energy sources. Among those are new methods of harvesting energy from the environment, ie, geothermal, solar and wind, or from man-made sources, such as mechanical vibration and heat [8], [9].

With the rise of Internet of Things (IoT), more devices, such as the sensors are connected to the internet for data gathering purposes. Energy harvesting from the environment is a good alternative to powering those sensors. Energy harvesting can be defined as the conversion of waste energy, such as vibration, heat, magnetism, solar and radio signals into electrical energy [10], [11]. Electrical energy in the form of Alternating Current (AC) can be harvested using piezoelectric and magnetism, while electrical energy in the form of Direct Current (DC) can be harvested using solar panels and thermoelectric devices.

Thermoelectric generator module (TEG) devices are well known in energy harvesting applications. They are low cost, small size and can be easily setup using differential temperature from heat waste generated from the engine, electric oven or combustion. The TEG module generates DC output. The module does the rectification process where alternative current (AC) is converted into direct current (DC). This effectively eliminates the need for a rectifying system, which is commonly used for AC to DC conversion.

In 1821, German physicist Thomas Johann Seebeck demonstrated that, when there is a difference of temperature at the junctions of two different metals, an electrical current is generated between those junctions (See Fig. 1). This phenomenon is known as the Seebeck effect. The thermoelectric generator works based on the principle of the Seebeck effect, and the formula of the output voltage is defined as:

$$V = S \times dT \qquad (1)$$

where,

V = voltage output

S = Seebeck coefficient in volts/°K

dT = differential temperature across TEG module, (Th-Tc)

Th =Thermal hot surface of TEG module.

Tc = Thermal cold surface of TEG module

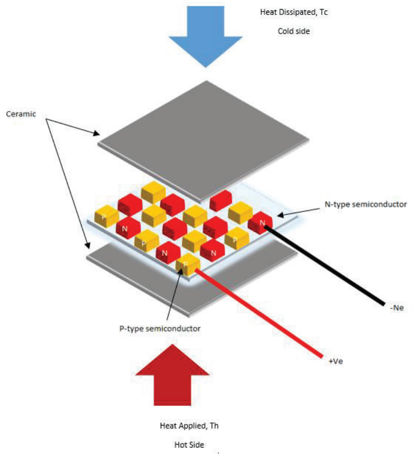

Fig.1. Schematic diagram of thermoelectric module

Audencial et al. (2018) and Champier et al. (2011) have demonstrated simple experiment setup procedure using thermoelectric generator module (TEG) which is vast scope in thermal energy, energy harvesting and thermoelectric [12]-[13]. This study is covered an experimental setup and characterization using single TEG module where TEG module was attached on the body of oven and built-in heatsink with cooler tank. The voltage output was analyzed in the graph for the optimum gradient temperature with the optimum resistance load to charge a 1.5V lithium-ion battery and power an LED torch light with power rating of 3W.

II. Methodology

The entire project consists of thermoelectric generator setup and high-speed data logger measurement device (Hioki: LR8400-20) which was used to measure the temperature in the hot and cold region of the TEG, as well the measurement of voltage, current and time for the entire experiment.

In previous work, the setup of the TEG using a heatsink but without the use of a cooler tank as heat dissipation for the desire of differential temperature dT of TEG [12]. To improve the differential temperature, dT of the TEG, a custom-made aluminum heatsink with a cooler tank was fabricated, and attached to the TEG module for the oven setup.

There are two hoses for water inlet and outlet in the cooler tank in order to prevent the thermal equilibrium of the TEG module with the body of the oven.

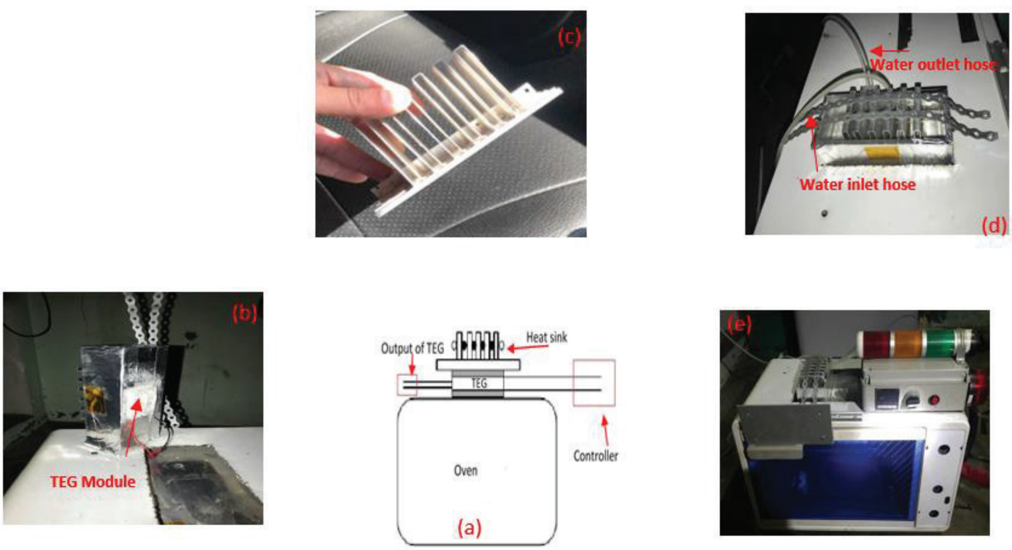

Fig. 2. Experiment Setup Diagram. (a) Block diagram; (b) Location of TEG Module; (c) Custom-made heatsink; (d) Water hose inlet and outlet; (e) Complete entire experiment setup

In this method, the water circulation of the cooler tank helps to maintain the differential temperature, dT of the TEG for the optimum voltage output of about 1.87 V. Fig. 2 summarized the steps of the TEG setup using one unit of TEG (Multicomp: MCPE1-12707AC-S) and controlled by a controller box which act as an on and off switch with timer function [13]. The experiment was carried out by raising the temperature in a controlled manner, from room temperature to 150°C in 60 min.

III. Results and Discussion

Fig. 3 shows temperature TEG of cold and hot region rise from the room temperature using kitchen oven in 60 mins with the differential temperature, dT.

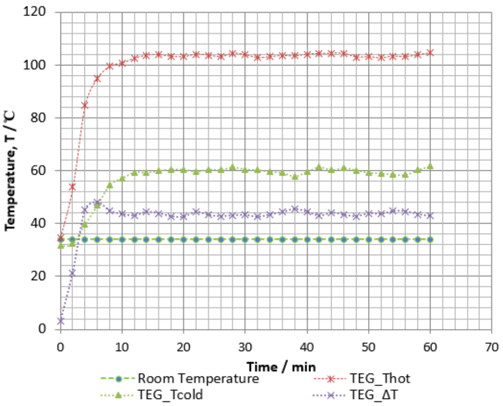

Fig. 3. Measured temperature distribution versus time

The maximum output voltage harvested graph plotted in Fig. 4 in 60 mins when using custom-made heatsink is about 0.92V while improvement heatsink with cooler tank is about 1.87V in open circuit using single TEG module. Then, the voltage output versus differential temperature, dT graph was plotted in Fig. 5.

The gradient of heatsink with cooler tank module about 0.0337 V/°C while non-cooler tank was 0.0757 V/°C. The lower gradient proven that heatsink with cooler tank improved output voltage when differential temperature, dT in higher value of temperature. The output voltage is directly proportional to differential temperature, dT of TEG. This is because the present of water circulation helps TEG module to gain higher value of differential temperature, dT.

Fig. 6 shows the power output of TEG with variance resistance. The optimum power drawn by TEG module is about 0.808W while the load is about 0.004 kΩ and it is able to power an LED.

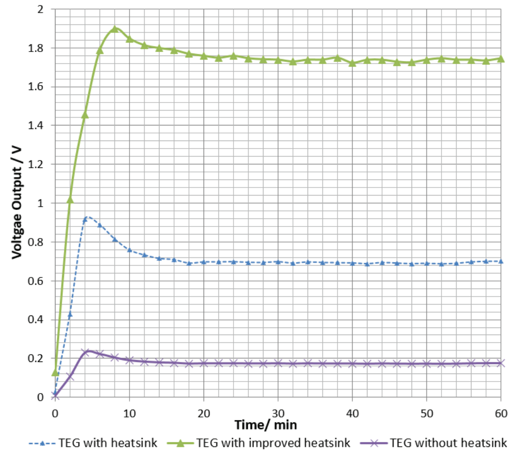

Fig. 4. Voltage output versus time

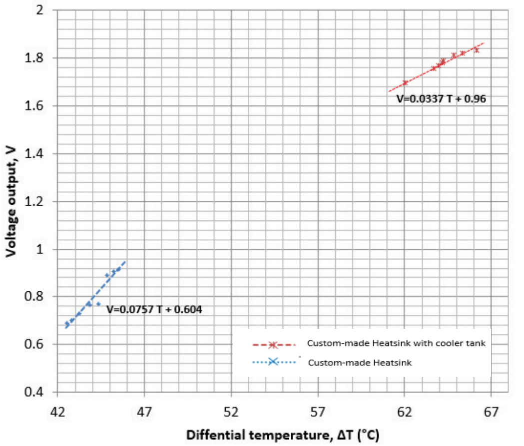

Fig. 5. Differential temperature versus voltage output

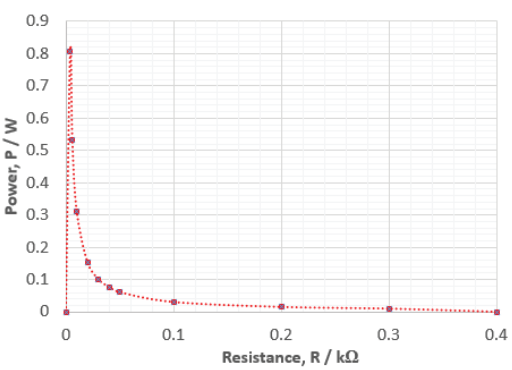

Fig. 6. Power output versus resistance

IV. Battery Charger Application

The experiment was further carried out to test the performance output of TEG whether it can be used in the system of battery charger application.

Fig. 7 shows block diagram of the battery charger where the output voltage of TEG is connected with step up DC-DC boost converter from 1.87V to 5V output for charging a lithium-ion battery 'AA" with capacity of 3500 mAH.

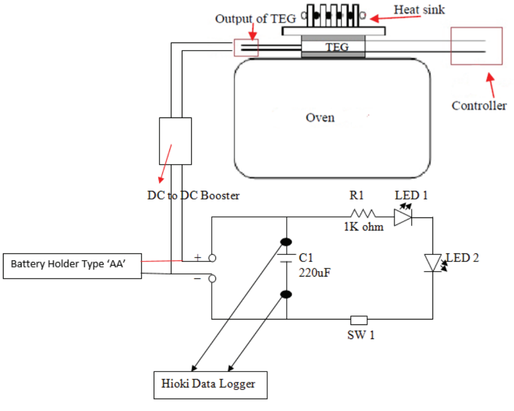

Fig. 7. Block Diagram of battery charger

The secondary circuit in Fig. 8 shows the output DC-DC boost converter is able to turn-on two LEDs using a simple RC circuit. Fig. 8 (a) shows the fabricated board of the system while Fig. 8 (b) shows the charging lithium ion- battery 'AA' was able to turn a LED torch light for 10 hours. Fig. 9 shows the TEG system takes about 110 mins to fully-charged the lithium ion- battery 'AA'.

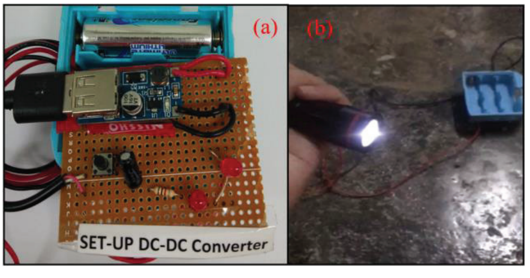

Fig. 8. (a) Fabricated boost up DC-DC converter; (b) Power-up the LED-torch light

V. Conclusion

In this paper, the battery charger application based on thermoelectric generator module from the heat waste of kitchen oven was successfully developed. The maximum voltage output was able to be harvested in the closed-circuit at about 1.87V using single TEG module where the gradient of TEG module was 0.0037V/°C. Future work will be carried out for the DC motor applications based on harvesting of the heat waste energy.

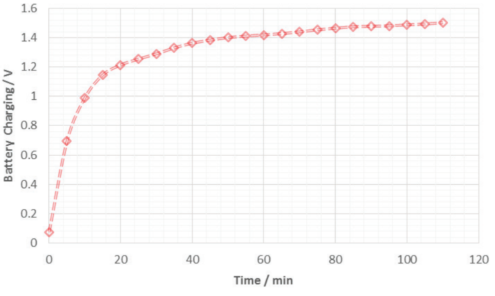

Fig. 9. Battery charging versus time.

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