Energy Recovery from Developed Food Vendor Stand using Thermoelectric Generator

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***Abstract:-*Thermoelectric generator is gaining more popularity in the world because it is environmentally friendly and converts waste heat to additional electric power using a temperature gradient between the hot and cold side. This research aims at designing and developing a charcoal powered food vendor stand equipped with a thermoelectric generator to light up the stand at night and generate useful electricity to power mobile devices especially mobile phones. The basic features include a charging station, Barbecue station and Cooktop. Mild steel was used in making the food stand, making it cost-effective. Test was performed between the hours of 10 am to 5 pm local time at every 5 minutes. 4 Channel digital data logging thermometer, connected to K-Type thermocouple was used to measure the temperature of the cooking pot, ambient temperature, as well as temperatures of the heat sink and conductor. Results showed that the power output increases as the difference in temperature between the hot and cold side increased. Also, the maximum power output of about 5 watts was generated from the thermoelectric generator and was used to charge up mobile devices and lights up a led lamp for work at night.**

***Keynote:* Temperature, Thermoelectric generator, power, energy, current, voltage.**

I. INTRODUCTION

In a developing country like Nigeria, majority of ruler dwellers and local street vendors uses woodfuel, charcoal and the likes as a source of fuel for cooking and heating. They also, burn kerosene and gasoline for lighting their stand at night which is relatively expensive, unavailable and results to environmental pollution. The utilization of these energies released is not fully underutilized due to excessive dissipation of heat to the environment. For the rural and urban poor, connection to the electricity supply is often prohibitively expensive or unavailable, even though the price of electricity itself may be low enough to encourage a switch to other fuels. As of the year 2003, less than 45% of the Nigerian population had access to electric power (Suleiman, 2011). In the words of (He, 2015), the generation of electricity in the world is mainly from fossil fuel-based power plant whose efficiency ranges 30 to 35% and a lot of waste heat is dissipated to the surrounding. The increase of innovation emerges the criticalness to present new choices for the generation of electricity. Numerous difficulties face the world to reduce waste thermal energy and fight global warming. Waste heat has a low temperature which makes it inadequate to be recovered and converted directly to electricity. A Thermoelectric generator defeats this issue because it is cheap and has no prerequisite for moving devices, for example, compressor, solution pumps and valves because the systems operate without working fluid. Besides, it has a high-temperature control precision (Riffat & Qiu, 2004; Atik, 2009; Brown et al., 2012). Thermoelectric generator alludes to coordinate the transformation of this heat vitality into electricity (Adroja, 2015). The used of thermoelectric generator is gaining more popularity in the world because it is environmentally friendly and convert waste heat to additional electric power using a temperature gradient between hot and cold junction without contaminating the environment. Also, this technology is simple and cheap since it has no moving parts which result in low maintenance cost and widely used in small scale application (Demir & Dincer, 2017). The use of this device in food vendor stands will not only reduce the cost of power generation and extra burning of fuel for the vendors but will provide a new function for the stands as a power generator, providing useable, clean electricity for lighting the stands at night by powering led lamps and charging mobile devices and power-banks. This is vital to enhancing productivity by extending working hours and enhancing communication by powering mobile devices. The use of the thermoelectric generator ensures that the heat energy harnessed from wood fuel is converted to electricity.

Thermoelectric generator can be utilized for cooling applications, aerospace, power generation, transportation, military and refrigerating system. Also, it enhances the efficiency of water heaters (Simons & Chu, 2000; Min & Rowe, 2006; Astrain, 2012; Baek et al., 2019; Li et al., 2019,.Li et al., 2018).

In the work of Muralidhar et al. (2018), an investigation was carried out on heavy-duty hybrid electric bus using TEC module. It was deduced that the emissions of CO2 and fuel consumption reduction were 7.58 and 7.2% respectively. A numerical method to determine the temperature of thermoelectric materials and optimization of the operating parameters of thermoelectric power generation was performed by Gomez et al. (2013). Nour et al. (2017) performed an analysis to ascertain the behaviour of TEG for marine application. Also, the heat transfer coefficient and system performance were investigated.

Yang et al. (2018) made used of fluent under dynamic temperature conditions to simulated regenerative and conventional thermoelectric generators. It was deduced that the variations of output voltage and temperature in the hot junction reduced by 86.45-89.16% and 86.46-87.71% respectively. An investigation to enhance the power materials for high-temperature thermoelectric generator was carried out by Bittner et al. (2019). Results showed that a high power density and electric power output would be obtained when the hot-side temperature and the temperature gradients increase. In the work of Luo et al. (2019), an investigation on the performance of an air-to-water thermoelectric generator was carried out using numerical and thermal resistance model. Results showed that thermal resistance model can be used to preliminarily evaluate TEGs performance while numerical model could also be adopted more precisely. A water-to-air thermoelectric generator was developed by Crane et al. (2004). It was deduced that a net power of 1 kW was obtained through the design of cross-flow heat exchangers. This research aims at designing a food vendor stand and thermoelectric generator to saving energy cost and utilizing available heat energy released from the stand to produce clean electricity for lighting and powering mobile devices using a developed system based thermoelectric generator.

II. MATERIALS AND METHOD

A. Selection of Materials

1. Frame

Mild steel was used in fabricating the frame for the charcoal food stand because it will ensure stability, toughness, high strength and rigidity to carry the fire pot, grill, charging station and the cooktop. Also, it is cheap, readily available and flexible using manufacturing.

2. Heat Sink

The heat sink is a vital part of the thermoelectric generator, it dissipates heat away from the thermoelectric unit, regulating the temperature even at optimal levels and maintaining the desired temperature gradient for a steady flow of electric current. Aluminium was used due to its high thermal conductivity of about 120 to 240 W/mK and can be extruded easily unlike copper.

B. Design

In designing the food vendor stand, special consideration was given to the assembly process and functionality. Here we designed a stand that can be quickly dismantled and assembled while being equally transportable. The Thermoelectric generator is also detachable for safekeeping and mobility and attached at will for electricity generation. In designing the food vendor stand, special consideration was given to the assembly process and functionality. Here we designed a stand that can be quickly dismantled and assembled while being equally transportable. The Thermoelectric generator is also detachable for safekeeping and mobility and attached at will for electricity generation.

1. Design of the Food Vendor Stand

The stand is designed to have three major areas;

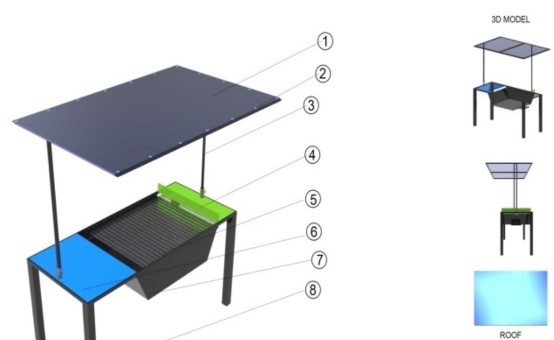
- a cooktop
- a barbecue station
- a charging station

The cooktop has an area 600 x 400mm for the food vendor to present and package food.

The barbecue station has an area 800 x 600mm for the actual preparation of food by direct exposure to radiant heat over a grill. This grill rests above a hot charcoal fire pot and is designed to slide freely across the frame enabling access to the fire pot for placement of charcoal and maintenance. The charging station is to the right of the vendor with an area 200 x 600mm upon which a multiple USB charge station is mounted and connected to the thermoelectric generator which is positioned at the lower right of the stand but in contact with the surface of the fire pot for power generation.

Other areas of importance include:

- Fire Pot: This is designed to carry the fuel (charcoal) and has a top surface area of 600mm x 800mm and a depth of 400mm. It is constructed out of mild steel with a side opening and mounts for the thermoelectric generator
- Roof: This is made up of a 900mm x1500mm thin sheet of metal riveted to a square steel pipe frame and two parallel 900mm shafts welded 300mm from both sides of the frame.
- Legs: There are four of these detachable supports about 800mm long hollow steel pipes which connect to the frame at the four corners providing support for the stand.



S/NO.	Item	Material	Quantity
1	Roof	Mild Steel sheet	1
2	Rivets		16
3	Roof Stand	Mild Steel	2
4	Charging Station	Mild Steel	1
5	Barbecue Station/Grill	Mild Steel	1
6	Cooktop	Mild Steel	1
7	Firepot	Mild Steel	1
8	Leg/Support	Mild Steel	4

Fig. 1 CAD Drawing of the Food vendor stand

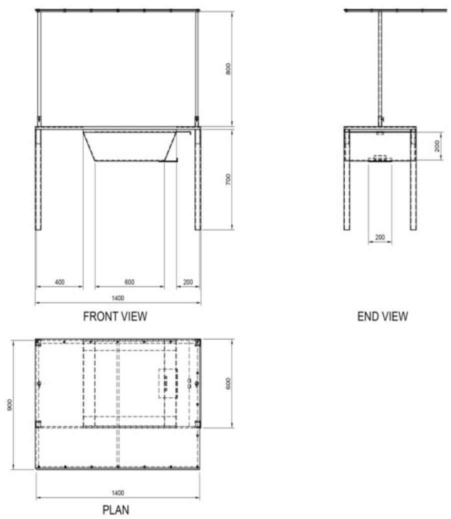
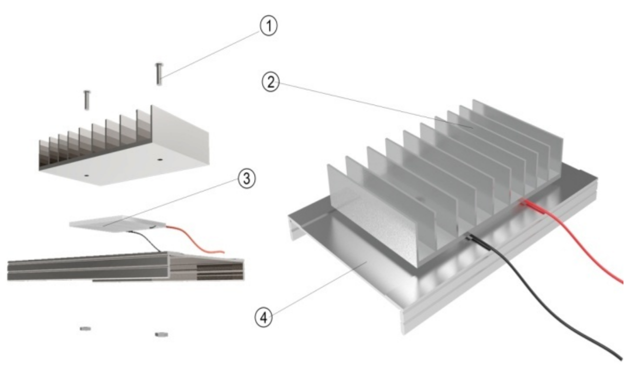


Fig. 2 Orthographic Drawing of the Food vendor stand

2. Design of the Thermoelectric Generator

The thermoelectric generator was designed with some specifications in mind. It should be able to power up most mobile devices and simple rechargeable led lamps with a 5V output USB cable. To achieve this, a small thermoelectric chip was obtained as a generator with an 8V open-circuit voltage, 800mA open circuit current, and temperature tolerance of above 200oC with a size of 40mm x40mm x 3.8 mm. This module generates the needed power and is easy to design around with the aluminium heat sink and aluminium heat conductor attached to maintain a desirable heat difference of 120oC for a steady power supply.

The size of the whole unit is 115mm x 75mm x 38cm when all parts are assembled. Also with most of it made up of aluminium, it is quite light, weighing about 0.2kg.



S/NO.	Item	Material	Quantity
1	Bolt	Steel	2
2	Heat Sink	Aluminium	1
3	Thermoelectric(TEG) Module	Bismuth/ Tellurium	1
4	CONDUCTOR	Aluminium	1

Fig. 3 CAD Model Drawing of the Thermoelectric Generator

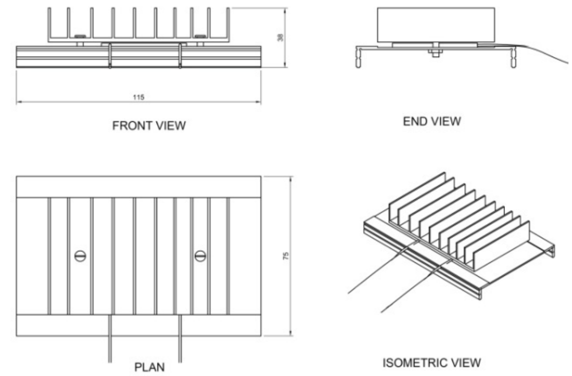


Fig. 4.Orthographic Drawing of the Thermoelectric Generator

C. Setup

To set up the Food vendor stand and thermoelectric generator,

- Fit the legs in place from below the frame
- Slot in the two roof shafts or posts and tighten using the bolts attached to hold the roof unit
- Place some charcoal in the firepot
- Slide in the grill from below the stations to rest above the firepot.
- Place the thermoelectric generator in its holder with the aluminium conductor touching the firepot surface when hot.
- Place mobile device or LED lamp on the charging station.
- Connect via USB to the thermoelectric generator when a bright red indicator light turns on.
- Leave the device to charge up.
- Disconnect when fully charged.

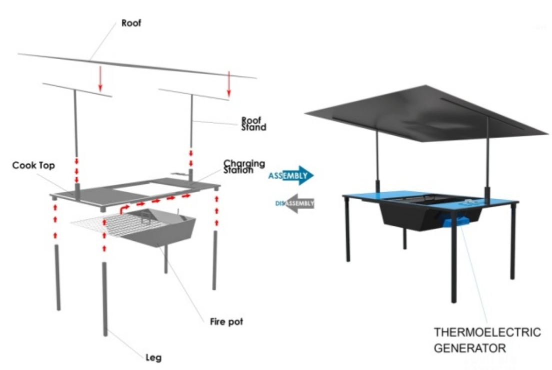


Fig. 5 Setup Illustration

D. Thermoelectric Calculations and Tests

1. Experimental Set-up/Procedure

- The tests were conducted between the hours of 10:00 am and 5:00 pm.

- The performance of the cooker was then tracked manually every ten minutes.
- 4 Channel digital data logging thermometer, connected to K-Type thermocouple was used to measure the temperature of the cooking pot, ambient temperature, as well as temperatures of the heat sink and conductor.
- The voltage and current generated were also measured
- The results were then logged every Two (2) minutes

E. Thermoelectric Charging Calculation

Considering the battery capacity of the mobile phone was 2,915mAh

One(1) TEG module generates averagely 0.381A,

Using four (4) modules=0.381 x 4=1.524A

Theoretically, this should take about;

Time (t) =(Battery Capacity(Ah))/current(A)

F. Average Power Calculation

Average Voltage, V from experiment=5.44V

Average Current, I from experiment=0.38A

Power, P = IV

=5.44 x 0.38

= 2.0672W

One(1) TEG module generates about 2.0672W

Using four(4) modules=2.0672 x 4= 8.2688W

III. RESULTS AND DISCUSSION

Fig. 6-8 shows the temperatures of an Aluminium conductor, heat sick and cooking pot. The result shows that the initial temperatures exceed 200oC for the Aluminium conductor and Heat sink, but there is a gradual reduction in the temperature with time as the charcoal burns to coal as shown in fig. 6 and 7 respectively. Also, the variation in temperature was attributed to humidity and wind direction of the surrounding.

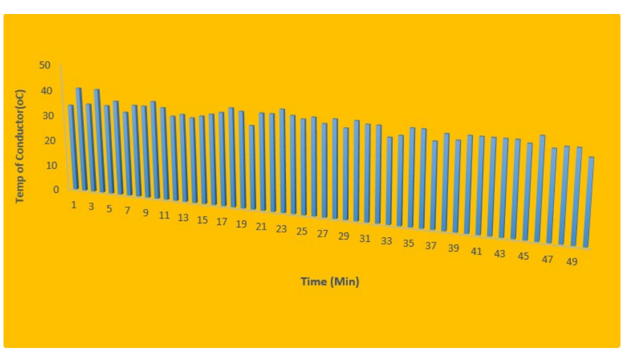


Fig. 6 Temperature change of the Aluminum Conductor (Th) with time

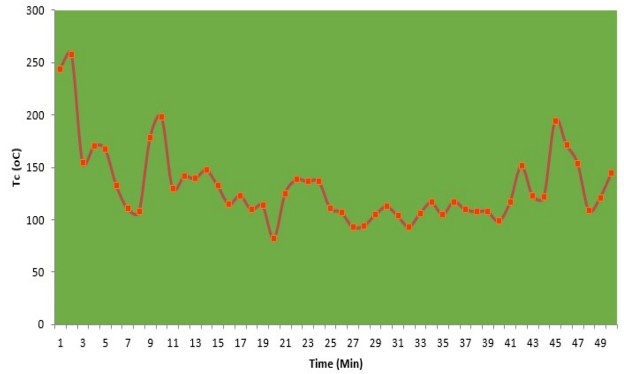


Fig. 7 Temperature change of the Heat Sink(Tc) with time

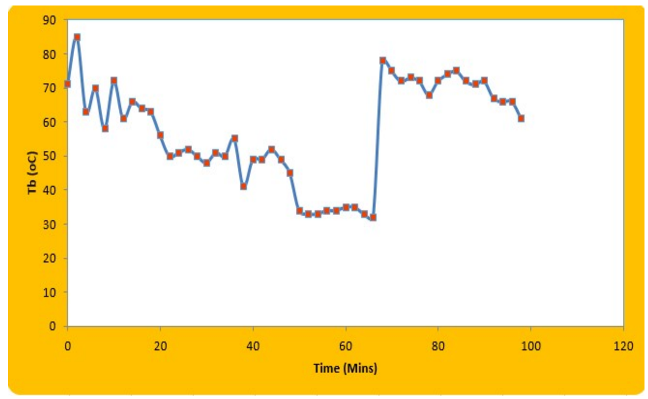


Fig. 8 Temperature change of the Cook pot body(Tb) with time

Fig. 9 shows the power generation from the temperature difference between the hot and cold side. It was deduced that the power output increases as the temperature difference between the aluminium conductor (hot side) and the Heat sink (cold side) increased. The temperature difference and power outputs were 54.4oC and 2.52Watts respectively.

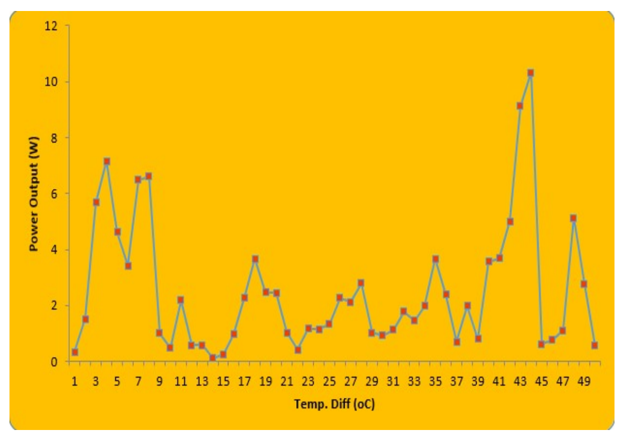


Fig. 9 Power output change with Temperature difference of TEG Module

Fig. 10 shows the electrical resistance per-interface against energy conversion efficiency. It was observed that the energy conversion efficiency decreases as the electric resistance per interfaces increased.

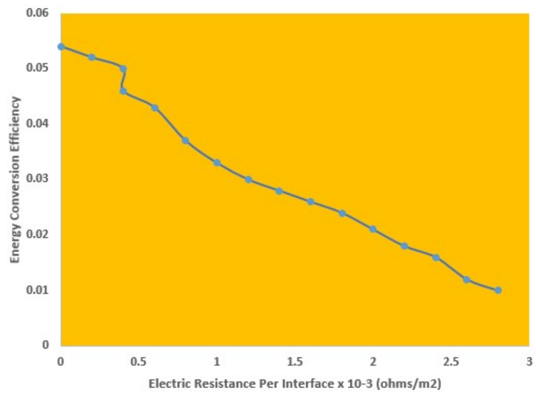


Fig. 10 Electricity Resistance per interface against Energy Conversion Efficiency

IV. CONCLUSIONS

The experiments with this model both for the Thermoelectric generator and the Food vendor stand have supported the following conclusions;

- Firstly, thermoelectric generators have a place in the Nigerian society today. They can be integrated into our street food vendor stands to harness useful energy.
- Secondly, this model can reduce energy cost for lighting food vendor stands to little above zero while been fully functional for preparing food.
- Thirdly, an added revenue stream and value can be made off food stands by charging mobile phones, power banks and LED lamps.

The result of this research provides great insight into the untapped manufacturing and industrialization of thermoelectric generating systems for public use here in Nigeria and Africa at large.

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CONFLICT OF INTEREST

Authors declare that there is no conflict of interest whatsoever.

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