Developing Work with the JUST Thermoelectric Stove by using Different Plate Materials at the Hot Side of the TEG

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Abstract Electricity nowadays is one of the most important things in people's life. However, there is a huge number of people in many regions who can't have access to electricity. Recently Thermo-Electric Generators (TEG) showed the potential to provide the basic amount of electricity for lighting, charging mobile and operating radios.

A JUST thermoelectric stove was tested in a previous work and not only showed a potential in producing electricity from biomass, but also could be used in cooking and heating water by utilizing the heat in the stack. This work tries to improve the efficiency of electricity production using the same stove. For this purpose, different base plate materials were compared to determine the most efficient plate in terms of heat transfer. A TEG assembly was connected on one side to the hot plate and a heat sink on the other side and the power output was measured and stored into a battery. The fuels used in this work were wood, manure, and peat which are available in deprived areas, and the plates were Aluminum, Galvanized Steel, Cast Iron and Copper (Bronze).

As experiments showed, Aluminum was the best plate material to transfer the heat to the hot side of the TEGs. The maximum matched power obtained from TEGs was about 1.05W, 0.95W, 0.71W and 0.46W for Aluminum, Galvanized Steel, Cast Iron and Copper (Bronze) respectively, with wood as fuel.

Keywords Thermoelectric stove, TEG, Biofuels, Plate material, Experimental measurements, Electricity deprived regions, Thermal conductivity, Multi-task stoves

1 Introduction

With the increase in energy demand and the expected shortage of the fossil fuel with time, the need for sustainable resources increases. Hence, this is initially handled by

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using clean fuels, utilization of waste heat [1, 2, 3] and adopting different configurations [4], where resources and environment are conserved. Among these options, the biomass energy is the most suitable source for the deprived and poor regions, because they already have the main material to produce energy from biomass.

The simplest way to extract the energy from the biomass is by burning them, to produce heat, which can be used to heat or generate electricity [5].

According to the *International Energy Agency* [6], an estimation of 1.2 billion people (16% of the global population) do not have access to electricity. More than 95% of those people living without electricity, are in countries in Sub-Saharan Africa and developing Asia. They are pre-dominantly in rural areas. See Table 1.

Our project will provide them with the basic amount of electricity for lighting, charging their phones, listening to radio and to operate some medical electronic devices. For sure, that will make a big difference in their lives.

TEG is one of the best choices to ingathering the waste energy and convert it into a useful power. A thermoelectric generator(TEG), also called a Seebeck generator, is a solid state device that converts heat (temperature differences) directly

Table 1 Global Electricity access in 2014.

SOURCE: IEA, world energy outlook 2016				
Electricity access in 2014 - Regional aggregates				
Region	**Population without electricity millions**	**Electrification rate %**	**Urban electrification rate %**	**Rural electrification rate %**
Developing countries	**1,185**	**79%**	**92%**	**67%**
Africa	634	45%	71%	28%
North Africa	*1*	*99%*	*100%*	*99%*
Sub-Saharan Africa	*632*	*35%*	*63%*	*19%*
Developing Asia	512	86%	96%	79%
China	*0*	*100%*	*100%*	*100%*
India	*244*	*81%*	*96%*	*74%*
Latin America	22	95%	98%	85%
Middle East	18	92%	98%	78%
Transition economies & OECD	**1**	**100%**	**100%**	**100%**
WORLD	**1,186**	**84%**	**95%**	**71%**

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into electrical energy through a phenomenon known as the Seebeck effect (a form of thermoelectric effect). Thermoelectric generators function like heat engines, but they are less bulky and have no moving parts.

As any renewable system energy, the main challenge or disadvantage is the efficiency of the TEG which is 10% [6], as maximum. Also, the price of the TEG is considered expensive relative to its efficiency.

On the other hand, one of the most advantages of the stove is that it doesn't need maintenance because there are no moving parts in it. Moreover, it will be workable day or night and will not be affected by the weather, the sun or anything else, like other systems as PV systems which work only in the sunny days. The latter will help us decrease the capacity of battery needed. We believe that will make our system more reliable.

JUST stove is a multi-tasking heater with a special design, making it useful for warming air, heating water, cooking and also generating electricity by using Thermo-Electric Generator (TEG) as shown in Figure 1.

The amount of generated electricity from the stove will be small, but it can be enough to cover the needed amount of electricity for charging phones, turning lights on or for running some medical electronic devices, which could make a difference in the lives of less fortunate people. Knowing that the amount of this electricity depends on the difference of temperature between the two sides of the TEG, but the hot side of the TEG will be connected to a plate (see Figure 2), so the mechanical and physical properties of this plate material will play a main role in heat transfer which leads to increase or decrease the amount of electricity produced.

In the previous work done by Najjar and Keseibi [7], the main objective was to determine the most convenient fuel type to use in the burning process, in addition to calculating the amount of energy produced to estimate the overall efficiency of the JUST stove.

The main objective of this work is to test the efficiency of four plate materials in term of heat transfer using the JUST stove coupled with twelve modules of TEGs in addition to use a battery to store the produced power. Experimentally, we will explore which plate material will be the most convenient for electricity production and the overall efficiency.

2 Equipment

In this section, we will show in detail, the main equipment used in the experiment such as the TEG, the plate material and the fuel.

2.1 Thermoelectric Generator Module

In our experiment, the TEG modules are sandwiched between the inside fins and the heat sink as shown below in Figures 3 and 4.

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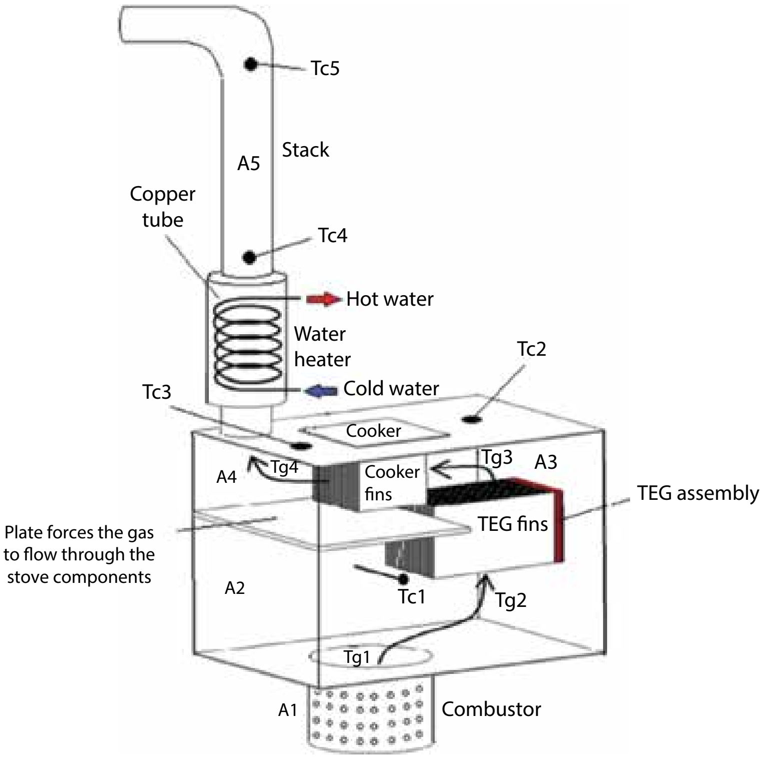

Figure 1 Cross Sectional View of the JUST Stove.

Tg1: Gas temperature at position 1
Tg2: Gas temperature at position 2
Tg3: Gas temperature at position 3
Tg4: Gas temperature at position 4
Tc1: Thermocouple at position 1
Tc2: Thermocouple at position 2
Tc3: Thermocouple at position 3
Tc4: Thermocouple at position 4
Tc5: Thermocouple at position 5
A1: Combustor zone
A2: After Combustor zone
A3: After TEG fins zone
A4: After cooker zone
A5: Stack

Table 2 and Figure 5 will show some details about the thermoelectric generator.

2.2 *Fuels*

Biomass is mainly consisting of cellulose, hemicellulose and lignin in addition to the basic elements of fuels such as Carbon, Hydrogen, Nitrogen and Oxygen [8].

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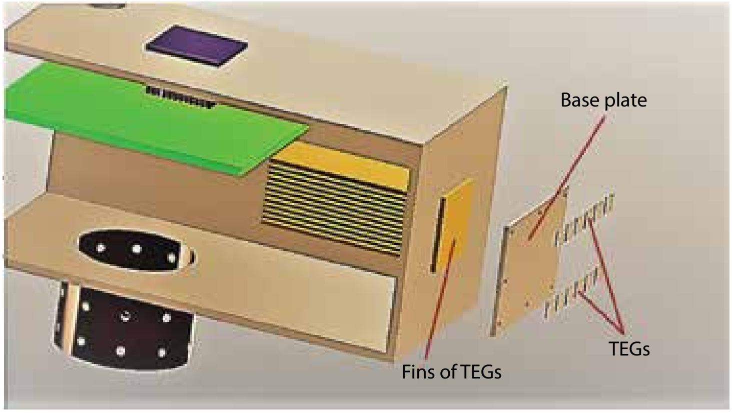

Figure 2 Side View of the Stove Shows the Base Plate.

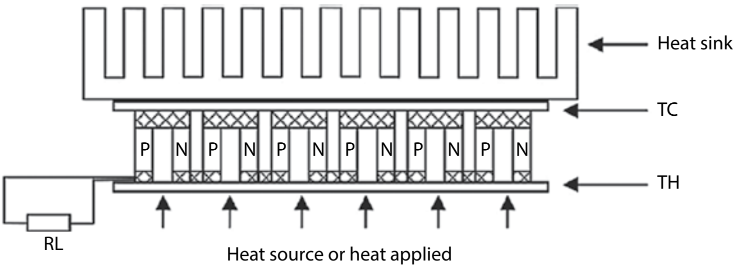

Figure 3 TEG Assembly.

Cellulose and hemicellulose are formed by long chains of carbohydrates, whereas lignin is a complicated component of polymeric phenolics. Lignin is rich in carbon and hydrogen, which are the main heat producing elements. Thus, its calorific value is higher than that of cellulose and hemicellulose (carbohydrates) [9].

According to the targeted region in this experiment, we had to choose specific types of fuel that are available naturally in the same environment. So, we chose wood, peat and manure (horses).

The Table 3 below shows some basic characteristics of these three types.

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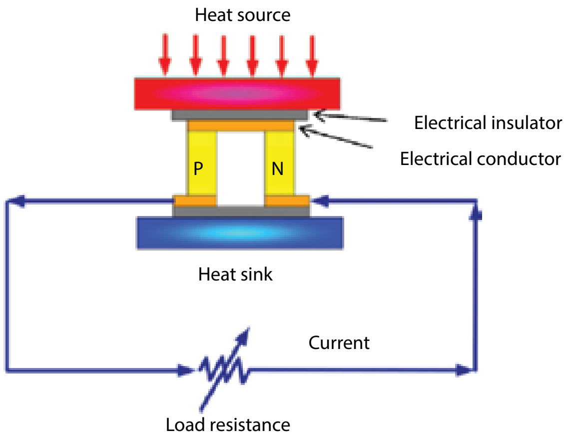

Figure 4 Side View of the TEG Module.

Table 2 TEG Module characteristics.

Module characteristic	*Symbol*	*Value*	*Unit*
Maximum power	P	3.21	W
Load resistance	R_L	6.8	Ω
Internal resistance	R_i	6.8	Ω
No. of semiconducting pairs	N	12	
Thermal conductance	U_{pn}	0.85	K/W

Other specifications from the manufacturer:
Model: SP1848-27145
Color : White
Material: Ceramic / Bismuth Telluride
Module weight: 25g
Module size: 4×4×0.34 cm (L×W×H)
Cable length: 30cm
Temperature difference: 20 degrees
Open-circuit voltage: 0.97V
Generated current: 225mA.[1]
Temperature difference: 100 degree.
Open circuit voltage: 4.8V
Generated current: 669mA.[1]

[1] The above values are for reference only, the wiring in actual use, and with the step-up board, there will be loss of current.

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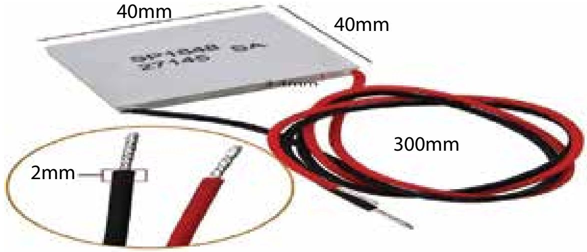

Figure 5 3D View of the TEG Module.

Table 3 Characteristics of the three fuels that were used in the experiment [7, 10].

Property	*Fuel*		
	Wood	*Peat*	*Manure*
Moisture content %	15%	20%	30%
Ash %	Trace	4%	11%
Theoretical air-fuel ratio	5.1	5.39	5.38
Net Calorific value (kJ/kg)	14350	14500	10600
Chemical composition	Carbon (42.5%) Hydrogen (5.1%) Nitrogen and Sulphur (0.9%) Oxygen (36.6%)	Carbon (43.7%) Hydrogen (4.2%) Nitrogen and Sulphur (1.5%) Oxygen (26.6%)	Cellulose (37.8%) Hemicellulose (32.4%) Liging (19.6%)

2.3 *Plate Materials*

The plate material plays the main role in electricity production using JUST thermoelectric stove. Many materials with different thermal characteristics can be used as plates but in this work only four materials (Aluminuim, Galvanized Steel, Cast Iron and Bronze) were tested for maximal heat transfer, Table 4. Shows the basic characteristics for the four plate materials. The plates were cut to have the dimension (35 × 25 × 4mm) as shown in Figure 6.

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Table 4 Thermal and electrical properties of the plate materials.

Material	Melting point (°C)	Thermal conductivity (W/m. °C)	Electrical resistivity (ohm.cm)
Aluminium [11]	660	210	2.70E-06
Bronze [12]	1010	91.2	1.20E-05
Cast Iron [13]	1150–1200	58	1.00E-04
Galvanized steel [14]	1370	52	1.70E-05

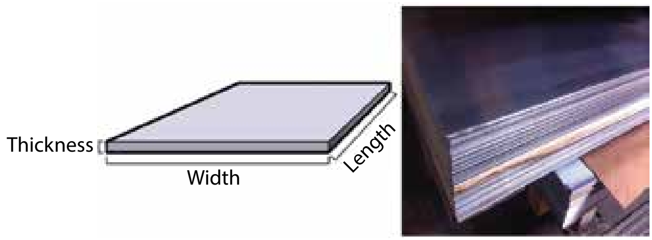

Figure 6 Aluminum plate.

2.4 *Measurement Devices*

This section shows the measurement devices that were used in the experiment.

2.4.1 Data logger

Data logger is an electronic device which automatically display and record environmental parameters over time, allowing conditions to be measured and documented, see Figure 7. The data logger contains a sensor to measure the parameters of interest and a computer chip to store the data. Then the information stored in the data logger is transferred to a computer for analysis. Data logger is used to record the thermocouple readings.

2.4.2 LM35 sensor

LM35 is a very sensitive IC temperature sensor whose voltage output is proportional to the temperature (in °C). The sensor circuitry is sealed and therefore it is not

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Figure 7 The data logger (TES1384) used to record the thermocouple readings.

Figure 8 LM35 sensor for temperature measurements.

subjected to oxidation and other external processes that might affect the measurement. The operating temperature range is from –55 °C to 150 °C. The output voltage varies by 10mV fo every 1 °C rise/fall in ambient temperature, i.e., its scale factor is 0.01V/ °C. It is used to measure the temperature of the plate connected to the hot side of the TEG. Figure 8 and Table 5 show some details about the LM35 sensor.

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Table 5 Pin description of the LM35 sensor.

Pin No	*Function*	*Name*
1	Supply voltage; 5V (+35V to -2V)	Vcc
2	Output voltage (+6V to -1V)	Output
3	Ground (0V)	Ground

Figure 9 Digital Multimeter for electrical measurements.

2.4.3 Digital Multimeter

A digital multi-meter (DMM) is an electronic device used to measure two or more electrical parameters, mainly current (amps), voltage (volts) and resistance (ohms), see Figure 9. It is a standard diagnostic tool for technicians in the electrical/electronic industries. It is used to measure the output current, voltage and resistance during the experiment.

3 Experimental Facility

3.1 Thermoelectricity (TE)

The first application of TE stove was developed in Sweden by the Royal Institute of Technology 1990 [15]. The prototype was used in the rural area of the country.

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They used two high power thermoelectric generators with wood burning stove for the purpose of increasing the temperature difference between the two sides of the TEG. They fitted a heat sink together with 2.2W fan. The power output ranged from 4–7W. The maximum power recorded was 10W.

Another study in this field was done by Nuwayhid et al, [16]. They used wood or diesel as fuel, their goal was to generate up to 100W electric power. They decided to use Peltier model to produce the electricity which is considered as a poor decision because Peltier model is made for cooling not for generating electricity. This decision led to produce only one Watt. So, in the second prototype they used three power generator models with 56*56 mm^2. These models were cooled by natural convection using heat sink. They got a maximum output power of 4.2W per model.

Lertsatitthanakorn [17] adapted a commercial thermoelectric model on the side of a biomass cooking stove and attached a rectangular heat sink to the cold side. He obtained an output power of 2.4W at a temperature difference of 150 **°C**. Thermo economic analysis showed that the payback period is very short.

Champier et al. [18] studied the use of thermoelectric generator to produce electric power to run a fan and ensure complete combustion and emit light. They installed a thermoelectric model with 56×56 mm^2 under the water tank which serves as the heat sink for the cold side and to ensure enough pressure for good contact in the assembly of the TEG model. They got a maximum power output per model of 6 W. In the second prototype [18] , they used a different thermoelectric model that works at higher temperatures. They connected the model with a switching electric regulator that stabilizes the fluctuating voltage from the model. They also modified the assembly of the thermoelectric model by reducing the thermal contact resistance by polishing the contact surfaces and applying compressive load to ensure enough pressure for good contact. They got a maximum output power of 9.5 W per model.

In fact there are many researches and studies concerning the harvesting of heat produced by combustion operations, and convert it into electricity [19]. We have just introduced some examples and in Table 6 there is a summary for the abovementioned models showing their cooling mode and maximum power per model [20].

3.2 *Experimental Set Up*

JUST stove was designed in a way to keep and use the largest portion of heat produced by burning the fuel. It comprises of a special aerodynamic chamber to produce heat. The produced heat is forced to flow through a specific path which starts from the fins of TEGs then into the fins of cooker before exhausting from the stack. These fins are used as a heat storage to deliver most of the heat to the plate which represent the base of hot side of TEGs. Fins of the cooker have the same function. Finally, at the beginning of the stack we put a water heater with a copper tube to heat the water for household use.

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Table 6 The cooling mode and the output power of the TEG.

Authors	Cooling mode	Max. power per model
Royal Institute of Technology in Sweden [15]	Forced convection (2.2W)	10 W
Nuwayhid et al. [16]	Natural convection	1 W
Nuwayhid et al.	Natural convection	4.2 W
Nuwayhid & Hmamde	Heat pipes cooling	3.4 W
Champier et al [18]	Water cooling	6 W
Champier et al	Water cooling	9.5 W
Lertsatitthanakorn [17]	Natural convection	2.4 W
Mastbergen & Wilson [21]	Forced convection(1W)	4 W
Raman P et al. [22]	Forced convection (0.83W)	4.5 W
BioLite	Forced convection(1W)	1-2 W
O'Shaughnessy et al. [23]	Forced convection(0.5W)	3 W.h/day
Najjar and Kseibi. [7, 10]	Natural convection	6.6 W

The output power depends on the difference of temperature between the hot and cold sides of the TEG. This difference will vary according to the type of fuel and the ambient temperature. The material of the plate also plays an important role in the efficiency of heat transfer, and this is the most important goal of this work, to compare between the performance of the different materials and determine the most efficient plate material.

3.3 Experimental Procedure

In this work, three types of fuel were used namely wood, manure of horse and Peat. Side by side, four different types of plate material were tested in terms of heat transfer while recording the power produced from each type. The steps of the experiment were done as follow:

1. Twelve modules of TEG were installed on the base plate which was connected to the fins in the behind side of the stove (one of the plates was selected as a base plate to doing the experiment with the three types of fuel individually).

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2. All positions of the thermocouples were checked (see Figure 1). Thermocouples, temperature sensors, and measurement devices were wired to record the data. The thermocouples used were K type, it is important to know the type of the thermocouples to adjust the setting of the Datalogger device.
3. A specific amount of fuel was burnt in the combustor while preparing sheets to record the data every specific period of time. To be more accurate, data had to be recorded every small period of time.
4. The valve of the cold-water tank was opened to allow the water to flow through the water heater and was collected again in another tank. For sure the temperature difference between the hot water and the cold water was measured to estimate the amount of heat transferred to the water, also to estimate the overall efficiency of the stove.
5. All previous steps were repeated with the other plate materials.
6. Finally, all data recorded from the experiment were represented in charts and a comparison for all types of plate materials to determine the material with the best efficiency.

The figures produced, will show the performance of the four different plate materials in term of heat transfer along the burning process. The expected curve will start increasing at the beginning of the burning process until reaches its maximum value then it will decrease to the end of the process.

3.4 Data Recording Procedure

Producing the maximum power from the TEG is achieved when the internal resistance of the TEG is equal to the load resistance. Achieving the previous condition is impossible during the battery charging process, so in this work, the battery was replaced by a variable resistance (potentiometer). The challenge was, how to determine the required value of the potentiometer?

Theoretically, at maximum power, the maximum voltage should be equal to a half of the open circuit voltage. So, the plan was to measure the open circuit voltage then immediately connect the potentiometer and change its value until getting the half of the open circuit voltage. At that point, the measurement devices were read the maximum current, voltage and resistance which led to obtaining the maximum power matched.

3.5 Sample Calculation for the Air Fuel Ratio:

The air fuel ratio can be calculated according to the equation:

$$AF = \frac{\dot{m}_a}{\dot{m}_f}$$

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Where $\dot{m}_a$ is the mass flow rate of the air, and $\dot{m}_f$ is the mass flow rate of fuel.

The mass flow rate of fuel can be calculated by dividing the net weight of the fuel burned by the time taken to burn it. For wood:

Initial weight = 1.6 kg

Final weight = 0.1 kg

$$\dot{m}_f = \frac{initial\ weight - final\ weight}{time\ in\ second} = \frac{1.6-0.1}{71\times 60} = 3.52\times 10^{-4}\ kg/s$$

The stoichiometric $\dot{m}_a$ for this amount of fuel should be 1.795×10^{-3} kg/s [24]

$$AF = \frac{1.795\times 10^{-3}}{3.520\times 10^{-4}} = 5.099$$

The same procedure could be followed for the other two fuels Peat and Manure [24]. The results are inserted in Table 3.

4 Results and Discussion

Figure 10 shows the behavior of the hot temperature on the hot side of the TEGs for the four types of plate material with wood. At the beginning of the burning process the aluminium plate shows better efficiency than the other plates but after 30 minutes the galvanized steel plate outruns the aluminium plate and shows better efficiency. The maximum value of temperature reached to 100 °C.

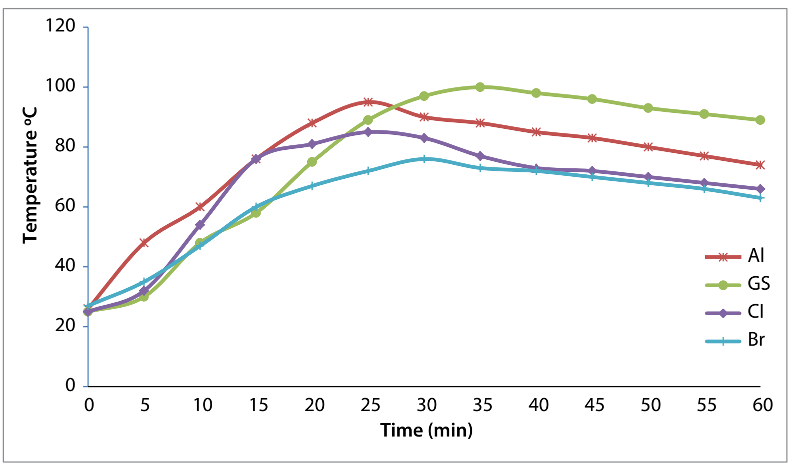

Figure 10 Profiles of T_H for different plate materials with wood as fuel.

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Figure 11 shows the behavior of the hot temperature on the hot side of the TEGs for the four types of plate material with peat as fuel. At the beginning of the burning process aluminium plate shows better efficiency than the other plates but after 25 minutes the galvanized steel plate outruns the aluminium plate and shows better efficiency. The maximum value of temperature reached to only 88 °C.

Figure 12 shows the behavior of the hot temperature on the hot side of the TEGs through the four types of plate material with manure as fuel. Aluminum plate shows better efficiency at the first half of burning process but at the second half

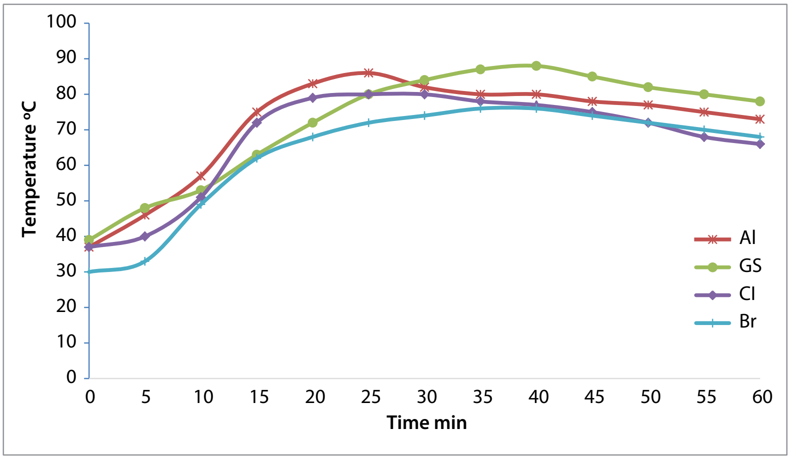

Figure 11 Profiles of T_H for different plate materials with peat as fuel.

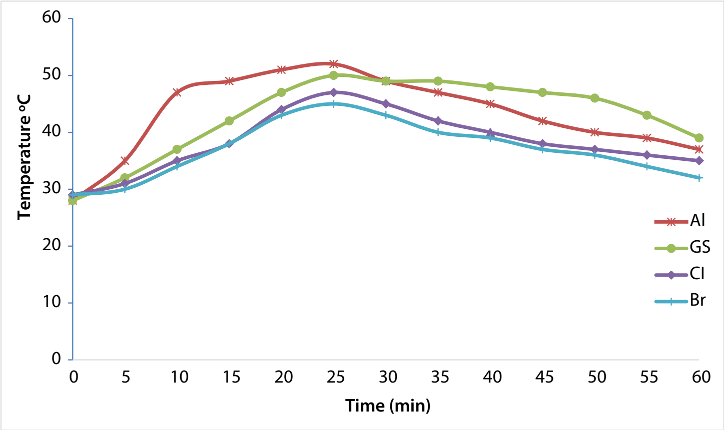

Figure 12 Profiles of T_H for different plate materials with manure as fuel.

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galvanized steel plate shows better efficiency followed by aluminium, cast iron then bronze. The maximum value of temperature reached to only 52°C.

Figure 13 shows the behavior of temperature on Aluminum plate material with all types of fuel. Wood has the highest values along the burning process followed by peat then manure.

Figure 14 shows the thermocouples reading for wood with aluminum plate material from initial ignition until 70 minutes of burning (see Figure 1 to determine

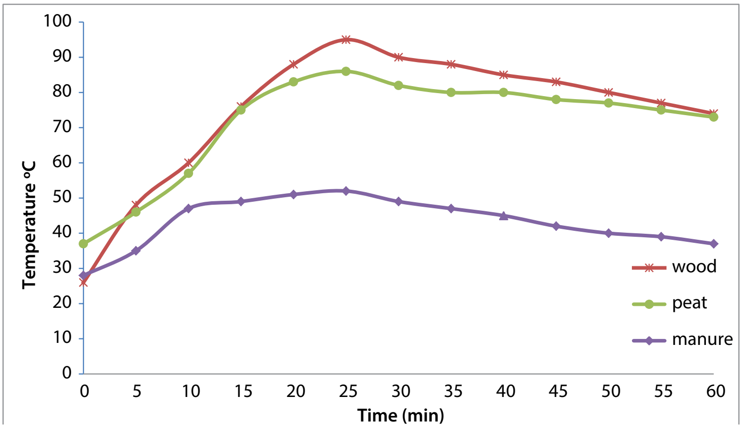

Figure 13 The behavior of T_H on Aluminum plate with all fuels.

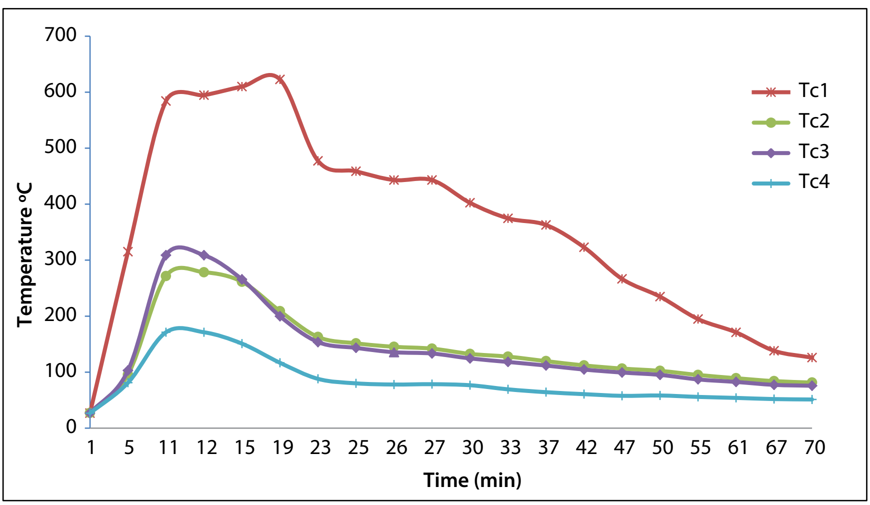

Figure 14 Thermocouple readings along the path in the stove for the combination of Aluminum with wood.

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the positions of the thermocouples). The temperature profile of all positions shows a sharp increase at the beginning of burning process then it goes down slowly until the end of the process.

Table 7 and Figure 15 show the performance of the TEG fins for wood with aluminum. The figure shows the increase of power and voltage at the beginning then they go down to the end of the process. The maximum point is after 26 minutes with maximum power of 1.05 W.

Table 8 and Figure 16 show the performance measurements of peat as fuel and Aluminum as plate material. The figure shows the increase of power and voltage in the first 15 minutes then they go down to the end of the process. The maximum point is after 13 minutes with maximum power of 0.86 W.

Table 9 and Figure 17 show the performance measurements of manure as fuel and Aluminum as plate material. The figure shows the increase of power and voltage in the first 17 minutes then they go down to the end of the process. The maximum point is after 16 minutes with maximum power of 0.11 W.

Table 10 and Figure 18 show the performance of the TEG fins for wood as fuel and galvanized steel as plate material. The maximum point is at time 30 minutes with max power of 0.92 W.

Table 7 TEG measurements using Al plate with wood as fuel.

Time(min)	T_H	T_C	ΔT	V_{max}(V)	I_{max}(A)	P(W)	R_{max}(Ω)
0	26.00	26.00	0.00	0.00	0.00	0.00	0.00
5	48.00	35.00	13.00	3.32	0.11	0.37	30.00
10	60.00	41.50	18.50	4.72	0.11	0.54	41.30
14	74.00	53.00	21.00	5.36	0.11	0.57	50.00
18	84.00	61.60	22.40	5.71	0.12	0.69	47.30
22	92.00	65.50	26.50	6.76	0.13	0.87	52.60
26	96.00	67.50	28.50	7.27	0.15	1.05	50.10
29	89.40	67.60	21.80	5.56	0.12	0.67	46.00
35	88.70	68.00	20.70	5.28	0.10	0.55	51.00
42	85.10	66.40	18.70	4.77	0.10	0.48	47.70
45	83.70	65.70	18.00	4.59	0.10	0.47	45.00
51	80.70	64.10	16.60	4.23	0.09	0.37	48.80
55	77.53	62.30	15.23	3.88	0.08	0.33	45.70
60	74.30	60.70	13.60	3.47	0.06	0.23	53.40
65	71.30	59.00	12.30	3.14	0.06	0.18	54.50
70	69.50	57.50	12.00	3.06	0.06	0.18	51.00

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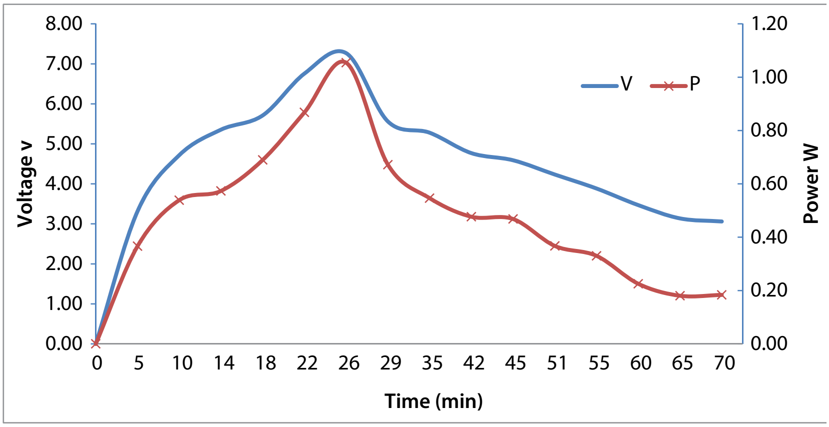

Figure 15 Output voltage and power vs time for the combination of Aluminm with wood.

Table 8 TEG measurements using Al plate with peat as fuel.

Time(min)	**T_H**	**T_C**	**ΔT**	**V_{max}(V)**	**I_{max}(A)**	**P(W)**	**R_{max}(Ω)**
5	44.80	31.50	13.30	3.39	0.09	0.30	38.20
9	55.60	37.40	18.20	4.64	0.11	0.49	44.00
13	67.80	44.30	23.50	5.99	0.14	0.86	42.00
17	76.40	52.70	23.70	6.04	0.12	0.73	49.70
22	81.10	60.00	21.10	5.38	0.11	0.60	48.20
27	80.70	61.00	19.70	5.02	0.11	0.53	47.50
32	80.80	63.00	17.80	4.54	0.09	0.39	52.80
37	80.50	63.40	17.10	4.36	0.09	0.41	46.50
42	80.10	63.80	16.30	4.16	0.08	0.33	53.00
47	79.00	63.40	15.60	3.98	0.08	0.32	48.70
52	77.10	62.40	14.70	3.75	0.08	0.30	46.10
58	74.50	61.40	13.10	3.34	0.07	0.22	50.50
63	71.40	60.00	11.40	2.91	0.06	0.16	52.70
70	68.30	57.80	10.50	2.68	0.05	0.14	53.00

Galvanized steel plate shows higher values in temperature than aluminum plate at the end of the burning process, but the temperature difference between the two sides of the TEGs were small at that period because the increasing of temperature of the cold side of the TEG during the burning process.

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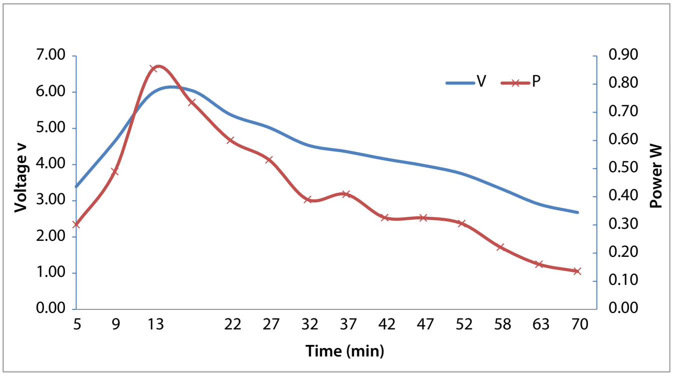

Figure 16 Output voltage and power with time for the combination of Aluminum with peat.

Table 9 TEG measurements using Aluminium plate with manure as fuel.

Time(min)	T_H	T_C	ΔT	V_{max}(V)	I_{max}(A)	P(W)	R_{max}(Ω)
5	35.00	31.00	4.00	1.02	0.02	0.02	50.60
10	43.50	35.00	8.50	2.17	0.04	0.08	58.90
16	48.50	38.50	10.00	2.55	0.04	0.11	58.00
20	53.00	44.20	8.80	2.24	0.04	0.08	60.20
25	51.00	43.80	7.20	1.84	0.03	0.06	58.50
30	50.90	43.90	7.00	1.79	0.03	0.05	59.50
40	47.00	41.00	6.00	1.53	0.03	0.04	57.00
50	43.80	38.00	5.80	1.48	0.03	0.04	55.00
60	40.00	35.00	5.00	1.28	0.02	0.03	56.50

The energy extracted from the experiment is small compared to other stoves for many reasons, the most important reasons are:

1. The method used to accomplish the experiment, where there was a battery charged directly from the electricity generated by the TEGs. The battery was replaced by a circuit simulated the impact of the battery, therefore the voltage measured was actually the maximum voltage which is equal to half of the open circuit voltage recorded in previous experiment. The current also will be low due to the high value of the load resistance. This

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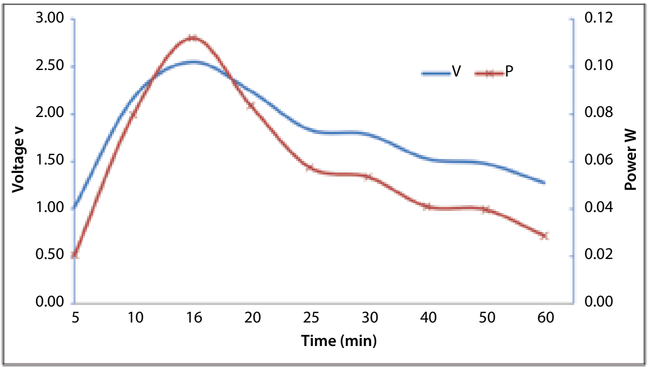

Figure 17 Output voltage and power with time for the combination of Aluminum with manure.

Table 10 TEG measurements using Galvanized steel plate with wood as fuel.

Time(min)	T_H	T_C	ΔT	V_{max}(V)	I_{max}(A)	P(W)	R_{max}(Ω)
0	25.00	25.00	0.00	0.00	0.00	0.00	0.00
5	30.50	27.00	3.50	0.89	0.02	0.02	41.50
10	48.20	35.30	12.90	3.29	0.08	0.25	43.00
14	57.90	40.60	17.30	4.41	0.10	0.42	46.00
16	64.50	47.20	17.30	4.41	0.07	0.32	61.00
18	68.00	50.00	18.00	4.59	0.08	0.38	55.30
20	75.00	56.70	18.30	4.67	0.07	0.35	62.50
25	89.00	64.00	25.00	6.38	0.11	0.69	58.80
30	97.00	67.00	30.00	7.65	0.12	0.92	63.50
36	101.00	72.50	28.50	7.27	0.12	0.88	59.80
43	98.70	72.30	26.40	6.73	0.12	0.79	57.70
47	96.00	71.00	25.00	6.38	0.11	0.67	60.70
55	91.70	68.70	23.00	5.87	0.10	0.61	56.20
60	89.50	67.00	22.50	5.74	0.10	0.59	55.60

is the main reason which explains the drop in the voltage and the power produced from the experiment.

2. The quality of the TEG used in the experiment and its maximum ability to produce the power, where there are other types able to produce more power at the same level of temperature difference.

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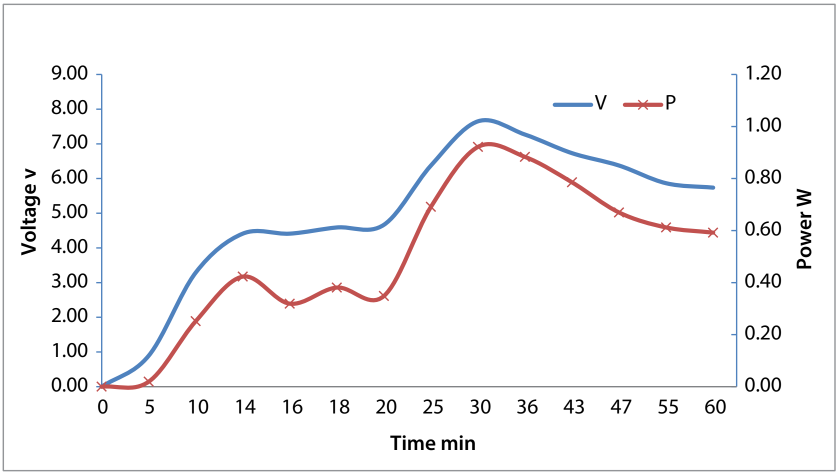

Figure 18 Output voltage and power with time for the combination of Galvanized Steel with wood.

3. The poor contact between the plate and the body of the stove causing the loss of convection in the heat transferred from the body of the stove to the plate and then from the plate to the hot side of the TEG.

5. Conclusions

This work tests the performance of four different plate materials in terms of heat transfer between the stove and the TEGs while storing the output power to a battery. It was found that:

1. Aluminum plate had the highest efficiency during the process, slightly better than Galvanized Steel, whereas Bronze had the lowest efficiency.
2. Many variables affected the temperature of the hot side of the TEGs, such as the thermal conductivity of the base plate material and the quality of the contact between the body of the stove and the base plate.
3. Charging a battery directly from the TEG assembly caused a drop in the voltage and the power output.
4. The produced power during the first 10 minutes of the burning process was low and not enough to charge the battery.

For possible future work, we encourage to use the DC-DC converter to boost voltage utilizing.

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Nomenclatures

Symbol

A	Surface area, m2
DMM	DMM Digital Multimeter
JUST	Jordan University of Science and Technology.
k	Thermal conductivity, W/mK
OECD	Organization for Economic Co-operation and Development
q	Amount of heat transfer, W
TEG	Thermoelectric Generator
TE	Thermoelectric

Subscripts

Al	Aluminum
Cu	Copper

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