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Thermoelectric Power Generation for Rural Communites in Nigeria Using Waste Heatfrom Palm Kernel Shell Pellets

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Abstract

In this article, a thermoelectric power generation for rural communities in Nigeria using waste heat from palm kernel shell pellets was studied. To generate electrical power, a thermoelectric generator (TEG) is attached between a heat source and a heat sink. Because of the temperature gradient created between the heat source and the heat sink, heat flows through the module and be rejected to the surroundings through the heat sink. An experiment was conducted using eight modules of TEG assembled and connected to a 60amps battery with no current. 1kg of biomass (palm kernel shell pellets) was measured and used as a heat source during the experimental analysis. From the analysis, 1kg of biomass (palm kernel shell pellets) was capable of generating the required temperature gradient created between the heat source and the heat sink, thus enabling heat to flow through the module and be rejected to the surroundings through the heat sink. The eight modules thermoelectric generator (TEG) generated 13.5V and 1022.65W power which can power simple electronic devices such as phones, radios etc. in rural communities in Nigeria.

1. Introduction

Waste heat is produced by several processes that make use of energy as well as machine which do work. The releasing of heat from various sources is based on the laws of thermodynamics. Several sources that produce heat are day to day activities, ecosystem etc. This waste heat can be utilized for generation of power with the help of thermoelectric power generator (TEG). TEGs have initial cost and efficiency of these devices is high, hence they can be used in various places to solve the problem of power generation [1]. A thermoelectric power generator (TEG) is a device that can convert thermal energy into electricity. It is a solid state heat engine and has no moving parts, no vibration and no noise, is light in weight and very reliable [2]. To generate electrical power, the TEG should be attached between a heat source and a heat sink. Because of the temperature gradient created between the heat source and the heat sink, heat will flow through the module and be rejected to the surroundings through the heat sink. According to [3], if the temperature gradient is maintained, electrical power will be continuously generated.

Direct thermal-to-electrical energy conversion of waste heat can be realized by using a TEG. The TEG can generate electrical power if it is placed between a heat source and heat sink. The basic phenomenon is called the Seebeck effect [4]. A TEG is small in size and requires no maintenance [5]. Although the current conversion efficiency of the TEG is low (less than 5%), several researchers have claimed greater performance, including the NASA Jet Propulsion Laboratory. They revealed obtaining more than 20% TEG conversion efficiency at a high operating temperature [5] and the results are significant enough to indicate that with the development of new TEG materials, direct power production by utilizing free energy from waste heat is economically viable and practical in the near future.

The thermoelectric module operation is based on the Seebeck effect Figure 1. According to [6], the Seebeck effect was discovered by Thomas J. Seebeck in 1821. He found that an electromotive force or potential difference (voltage) could be generated by a circuit made from two different wires if one of the junctions was heated. In a thermoelectric module, when two dissimilar conductor are connected and the two junctions are maintained at temperature TH and TC where $TH > TC$, an open circuit electromotive force or potential difference (voltage) is developed between this junctions. The electric voltage is proportional to the temperature difference and is given in Equation 1.

$$U = (TH - T) \qquad (1)$$

Where α is the Seebeck coefficient and is measured in μV/K.

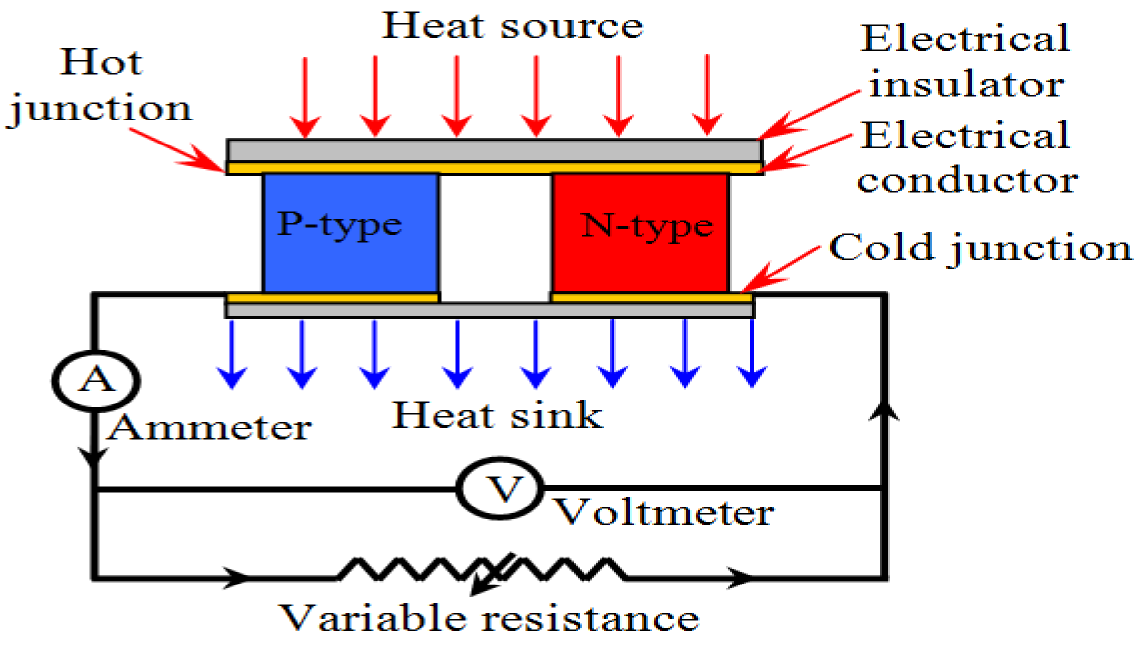

Figure 1: Thermoelectric Module Operation

A number of researchers have developed theoretical models in order to investigate the performance of the thermoelectric generator. For example, [7, 8] fabricated a TEG system which was clamped between aluminium plates. Hot water at 95°C flowed at the centre of a cold extrusion container of size 86 x 23 x 350 mm. On the cooling side, 20°C cold water was maintained through both ends of the container. The TEG power and voltage output were presented as a function of temperature difference of the hot and the cold water. The efficiency of TEG increased with the temperature difference.[7] developed a passive heat transfer and heat to work conversion system for simultaneous heat recovery and power generation.

[9] developed a theoretical model of a waste-heat thermoelectric power generator which included analysis of both internal and external irreversibility effects. This analysis method was considered more real because it provided actual generator specific power and efficiency estimation rather than ideal values. [10, 11] have established an optimization procedure to evaluate the performance of thermoelectric modules for power generation. This analysis correlated the module geometry with the requirements for obtaining maximum power output and conversion efficiency. [12] have analysed the performance of a thermoelectric generator by studying the effect of heat exchanger geometry, fluid volume flow rate, fluid properties and fluid inlet temperatures. [13-16] has performed a heat transfer irreversibility analysis to investigate the performance characteristics of a multi element thermoelectric system. This study intends to generate thermoelectric power for rural communities in Nigeria using waste heat from palm kernel shell.

2.0 Methodology

2.1 Materials for Experiment

The materials needed and used for the experimental analysis are as follows: thermoelectric modules, temperature logger, biomass burner, inverter, 60amps battery, palm kernel shell, voltmeter, thermal paste, extension wire, bulbs.

2.2 Experimental Set-up and Analysis

The experiment was conducted to investigate the amount of electric power output of eight assembled thermoelectric generator using a biomass (palm kernel shell) as the heat source. 1kg of palm kernel shell was placed into the burner and 0.2litres of kerosene was sprinkled into it for the initial ignition of heat. The flame of the palm kernel shell was allowed to come up after 10minutes. The assembled unit of the thermoelectric generator was connected to an uncharged 60amps battery as highlighted in Figure 2. Meanwhile, thermal paste was applied on the surface of the copper wire connected from the assembled thermoelectric unit to the battery so as to reduce heat transfer from the burner to the wire. The assembled thermoelectric generator was thereafter placed on the burner as depicted in Figure 3.As soon as the assembled thermoelectric generator was placed on the burner, water was supplied for cooling through the inlet (vertical) and comes out through the outlet (horizontal) into a bucket. Meanwhile, a temperature logger was used to take the temperature of the cooling water, T_L in the bucket and the burner T_H. As the temperature of the biomass gets hotter and increases, the temperature of the cold water also increases. At some point, the temperature of the cooling water and the heat source becomes stable and begins to drop as a result of reduction in mass of fuel energy (palm kernel shell). As the 1kg palm kernel shell exhausted, the battery was disconnected from the assembled thermoelectric generator. Figure 4 shows that electric bulbs were connected to the set-up to indicate power output and a voltmeter was used to measure the voltage in the battery. The final reading was taken and was 13.5volts.

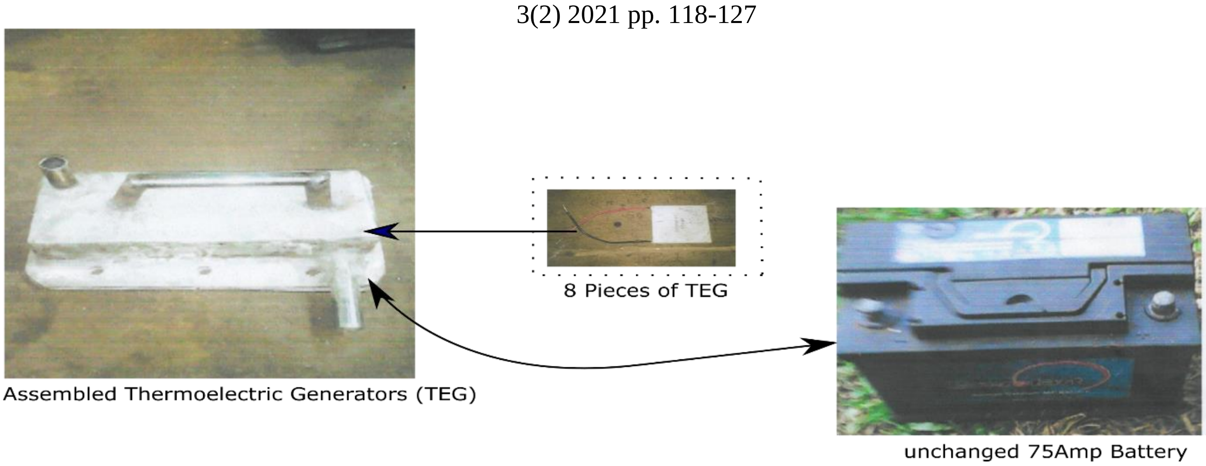

Figure 2: Thermoelectric modules connected to 75Amp Battery

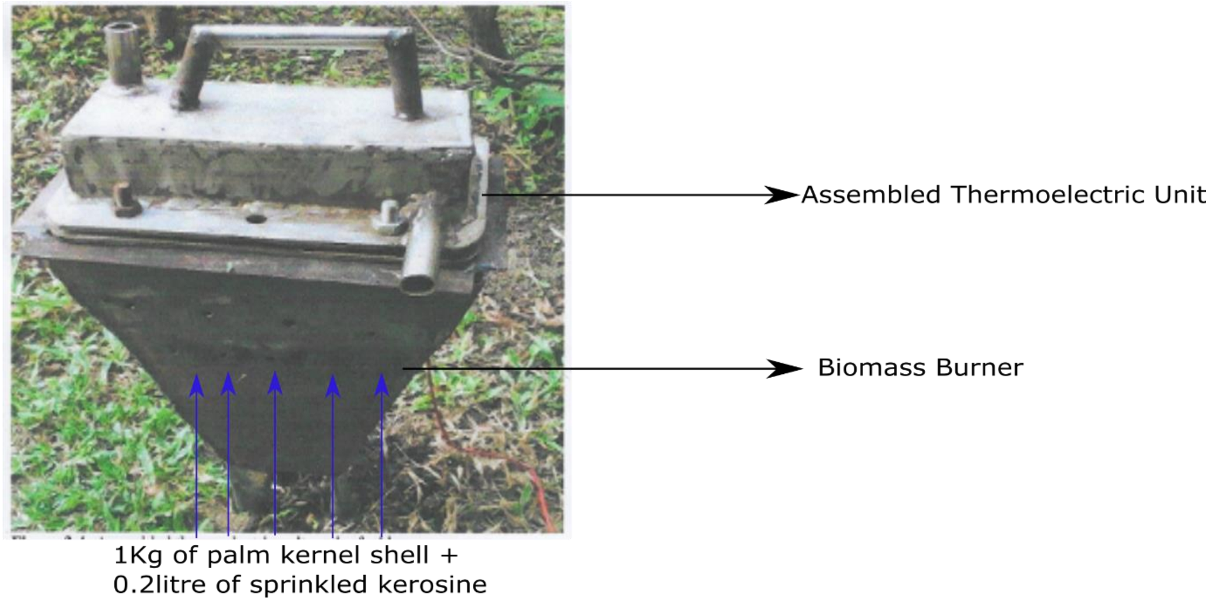

Figure 3: Assembled TEG placed on the shell burner

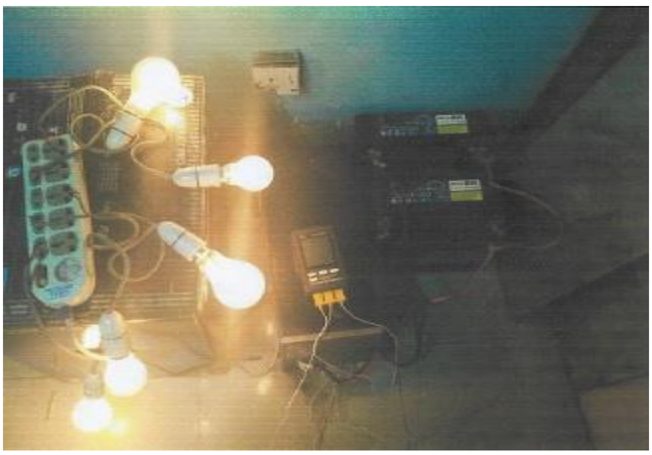

Figure 4: Performance Testing using 200W Electric Bulbs

2.3 Experimental Equations for Data Analysis

Equation (2) is the voltage equation to calculate the flow of current, while Equation (3) is the power equation and used to determine the power output.

Voltage Equation: $V = \alpha (T_H - T_L) + IR$ (2)

Power Equation: $P = \alpha I (T_H - T_L) + I^2R$ (3)

Where,

α = Seebeck coefficient = 0.01229V/k

T_H = Temperature of heat source (palm kernel shell)

T_L= Temperature of heat sink (water)

R= Internal resistance = K_m = 0.1815W/k

2.3.1 Data Presentation

Table 1 shows the data obtained from the experimental analysis.

Table 1: Data obtained from experimental analysis

No of readings taken	$T_{L(Water)}$ °C	$T_{H(Biomass\ fuel)}$ °C	$T_H - T_L$	Voltage (V)
1.	38.6	25.6	-13	0.5
2.	40.1	26.9	-13.2	1.25
3.	43.4	32.7	-10.7	1.68
4.	44.6	32.9	-11.7	2.05
5.	47.6	33.0	-14.6	2.58
6.	48.7	33.8	-14.9	2.92
7.	50.8	36.5	-14.3	3.56
8.	54.2	37.6	-16.6	4.37
9.	55.2	37.7	-17.5	5.79
10.	57.7	38.6	-19.1	6.68

11.	58.1	39.4	-18.7	7.90
12.	60.1	43.0	-17.1	8.95
13.	62.3	43.1	-19.2	10.25
14.	63.0	43.1	-19.9	11.4
15.	63.2	43.0	-20.2	12.1
16.	63.1	42.8	-20.3	12.9
17.	62.7	42.5	-20.2	13.5

3.0 Result and Discussion

3.1 Current Flow Analysis

Equation (2) was used to analyse the current output using the corresponding voltage at each stage.

$V = \alpha\,(T_H - T_L) + IR$

$0.5 = 0.01229\,(25.6 - 38.6) + I\,(0.1815)$

$I = 3.635A$

The first voltage reading of 0.5V was determine and gave a corresponding current of 3.653A. Other calculations were determined the same way and shown in Table 2.

Table 2: Result of Current Flow

No of readings taken	Voltage (V)	Current (A)
1.	0.5	3.635
2.	1.25	7.78
3.	1.68	9.98
4.	2.05	12.09
5.	2.58	15.20
6.	2.92	17.10
7.	3.56	20.58
8.	4.37	25.20
9.	5.79	33.09
10.	6.68	38.10

11.	7.90	44.79
12.	8.95	50.19
13.	10.25	57.63
14.	11.4	63.99
15.	12.1	68.08
16.	12.9	72.45
17.	13.5	75.75

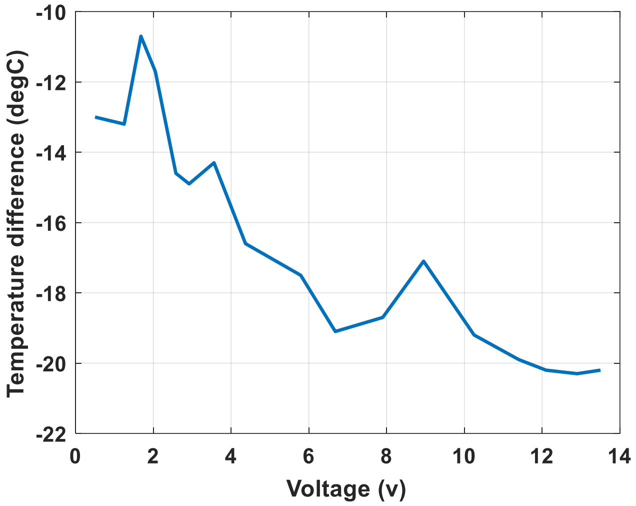

Figure 5: Temperature difference (^oC) against Voltage (V)

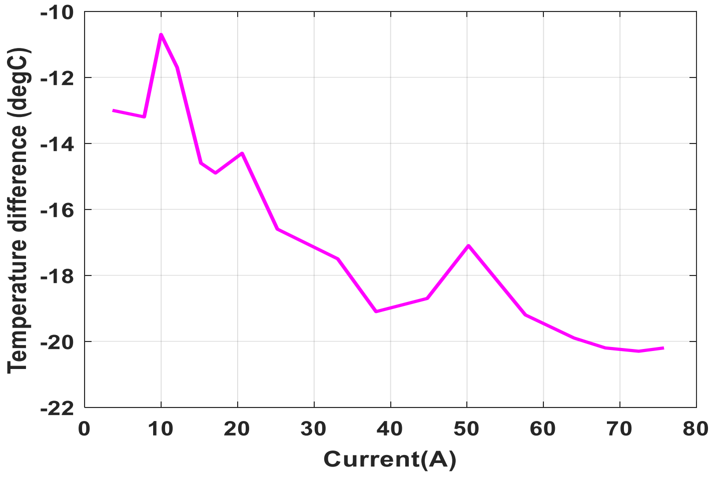

Figure 6: Temperature difference (^oC) against current (A)

From Figure 5 and Figure 6, it was observed that the measured voltage as well as the current flowing in the system is affected by temperature gradient between the heat source and heat sink.Which clearly indicate that higher temperature difference yields low voltage and current respectively, and vice versa.

3.3 Power Output Analysis

Equation (3) was used to analyse the power output using the corresponding current at each stage.

$P = \alpha I\,(T_H - T_L) + I^2R$

$0.01229 \times 3.635\ (25.6 - 38.6) + (3.635)^2\ (0.1815)$

$P = 1.82W$

The first current of 3.635A was used to determine the corresponding power of 1.82W. Other calculations were determined the same way and shown in Table 3.

Table 3: Data obtained for power output

No of readings taken	**Current (A)**	**Power Output (W)**
1.	3.653	1.82
2.	7.78F	9.72
3.	9.98	16.77
4.	12.09	24.79
5.	15.20	39.21
6.	17.10	49.94
7.	20.58	73.25
8.	25.20	110.12
9.	33.09	191.62
10.	38.10	254.52
11.	44.79	352.82
12.	50.19	446.66
13.	57.63	590.69
14.	63.99	729.43
15.	68.08	823.74

16.	72.45	934.62
17.	75.75	1022.65

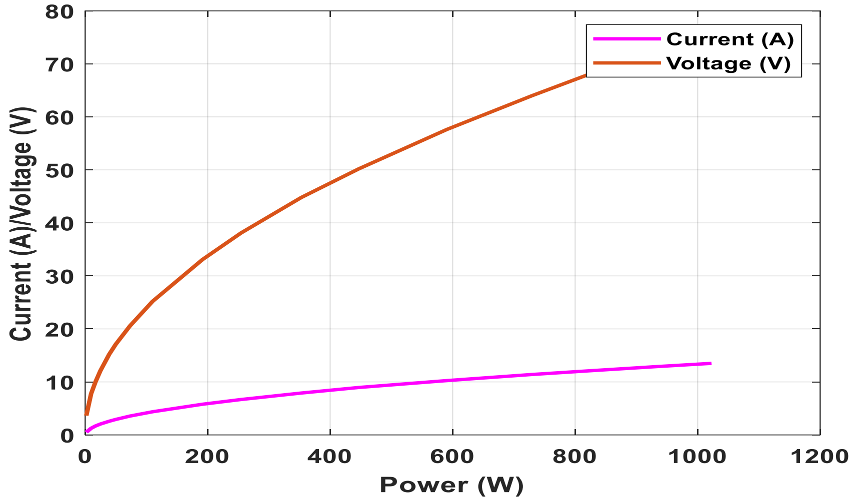

Figure 7: Current (A)/Voltage (V) against Power output (W)

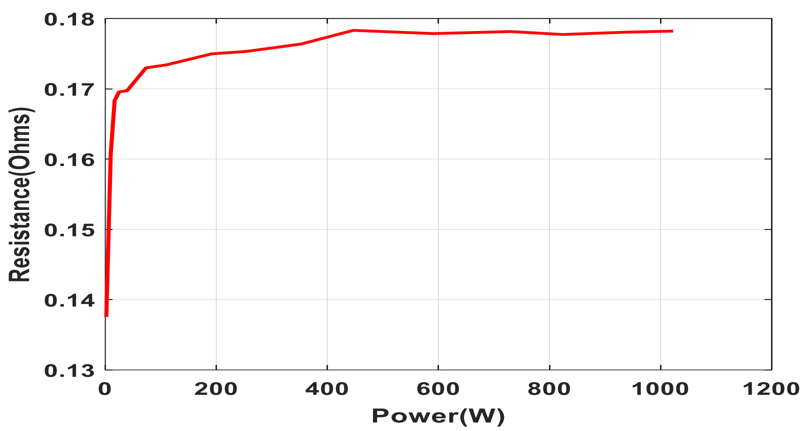

Figure 8: A plot of Resistance (Ω) and Power generated (W)

The power generated by the TEG is directly affected by the measured voltage and the evaluated current. As observed in Figure 7, with increase in both quantities, the power output increased. The relationship between the power output and the resistance to the applied current is highlighted in Figure 8. This resistive effect was observed to be very significant at power output below 100W. Thereafter, this variation sharply reduced and became almost constant when about 450W power was realized. A maximum power of 1022W was realized at the peak resistance of 0.178Ω. Essentially, from the experimental setup and analysis, it shows that 1kg of biomass fuel (palm kernel shell) can produce the desired temperature gradient needed to establish and generate the voltage and power output. Furthermore, in Table 1, it was also observed as the voltage increases, so is the current. Also in Table 2, it was alsoobserved that current and power output is also increasing simultaneously. This again means that with 1kg of waste heat from palm kernel shell, 13.5V and 1022.65W can be generated.

4.0 Conclusion

This study assembled eight thermoelectric modulesusing waste heat from palm kernel shell pellets as heat source. It study established that 1kg of biomass (palm kernel shell pellets) is capable of generating the required temperature gradient created between the heat source and the heat sink, thus enabling heat to flow through the module and be rejected to the surroundings through the heat sink. The eight module thermoelectric generator (TEG) is capable of generating 13.5V and 1022.65W power which can power simple electronic devices such as phones, radios etc. in rural communities in Nigeria.

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