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# Evaluation of experimental JUST thermoelectric stove for electricity – Deprived regions

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ABSTRACT

Access to electricity is one of the important challenges for developing countries. Adding TEG (thermoelectric generator) can provide electricity for the basic needs such as: radio, light, phones and other small medical electronic devices. In this work, experiments are carried out on a specially designed stove using three types of solid fuels. It explores the role of the stove in the real life of poor remote areas deprived of electricity. These fuels include wood, peat and manure.

The stove consists of a combustor with special aerodynamic design. Moreover, a thermoelectric generator (TEG) and a cooker plate are fitted with specially designed fins for enhancing heat transfer and keeping the stove small size. The hot water coil is fitted, after them at the beginning of the stack.

Performance results obtained from experiments were compared with those from the theoretical model. The maximum matched power obtained from TEG was about 5.7 W, 6.6 W and 1.8 W for wood, peat and manure, respectively. The maximum overall efficiency is 65% when using peat.

## 1. Introduction

Fossil fuels are considered the dominant source of energy. They satisfy the energy demands of society. However, the major drawbacks are that fossil fuels resources and locations availability are getting more and more limited. Therefore, new resources are proposed for alternative energy sources, such as solar, wind and biomass and hydrogen energies [1] in addition to utilizing waste heat [2–5], energy storage [6,7]. Biomass energy comes first in deprived and poor regions. It depends on what these regions got from humans and animals residues, in addition to woods, peats and grass. This leads to sustainability and independence from other energy sources. Biomass can be converted directly into heat that is utilized into useful energy for heating, cooking and producing electricity. Biomass has the potential to reduce the emissions and enhances carbon sequestration due to short rotation crops established on abandoned agricultural land and accumulated carbon in the soil.

1.3 billion People – about 20% of worldwide population – are still without access to electricity, almost all of whom live in developing countries [8]. Providing a minimum amount of electricity can actuate the basic needs such as light, radio and some medical electronic devices. Thus, making a lot of difference in their lives. TEG coupled to the stove can be a very interesting option to provide such amount of electricity.

TEG is a device that harvests waste energy and convert some of it to useful power. It operates on a fundamental principle termed the Seebeck effect which states: when a temperature gradient is established between two different metals or semiconductors, a corresponding voltage gradient is induced. This causes a continuous current to flow through a complete circuit.

The major advantage of a TE generator in this case is requiring almost no maintenance, since there are no moving parts. Only the battery needs to be charged when needed. The TE generator works day and night in clear or rainy weather unlike solar panels. Moreover, the battery does not need to be oversized. On the other hand, there are some challenges involved in using the thermoelectric generators. Mainly the low efficiency of the technology itself is below about 10% [9] and the high price of the TEG models. The low efficiency problem may be solved by new technologies evolved over time. The price will decrease with more adoption of such systems.

After reviewing the previously designed and tested stoves [10–19,20,21], a multi-task thermoelectric JUST stove (Jordan University of Science and Technology Stove) was designed and tested to help the people living in remote poor regions and deprived of electricity. This JUST stove serves the purposes of space heating, cooking and water heating besides producing electric energy by using TEG. The latter will serve different aspects of life including: lighting, charging the cellular phone, listening to the radio and operating some medical instruments

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**Nomenclature**

| | |
|---|---|
| JUST | Jordan University of Science and Technology |
| N | number of thermoelectric models |
| P | electric power (W) |
| $R_l$ | load resistance (ohm) |
| $R_i$ | internal resistance of one TEG model (ohm) |
| $S_{pn}$ | Seebeck coefficient (V/K) |
| TEG | thermoelectric generator |
| $T_c$ | cold side temperature of the thermoelectric model (K) |
| $T_g$ | gas temperature (K) |
| $T_H$ | hot side temperature of the thermoelectric model (K) |
| $U_{pn}$ | thermal conductance (W/K) |
| $V_{oc}$ | open circuit voltage (V) |
| 1–5 | positions of the gas path along the stove |

and much more.

Hence, the objective of this work was to design, construct and test a stove with 12 TE modules coupled to it in order to generate electricity, evaluate the power output, efficiency and compare the results with other stove models. The design covered the whole components including the combustor with special aerothermal design. The fins of both TEG and cooker. TEG base and heat sink and the cooker were designed to give optimum spacing and performance. Water heater was designed with a copper tube exposed to the exhaust gases to recover most of the remained energy. To simulate the real circumstances of those living in remote areas, different fuels including wood, manure and peat were utilized. Heat transfer analysis was especially considered with JUST stove as a case study.

Champier et al. [14] 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 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 [15] 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. They got a maximum output power of 9.5 W per model.

For the JUST stove, the power was expected to be about (3.7 W) from each TE module at standard specifications. Experimental measurements were compared with the results of theoretical analysis using TE and heat transfer models. The comparison was very favorable.

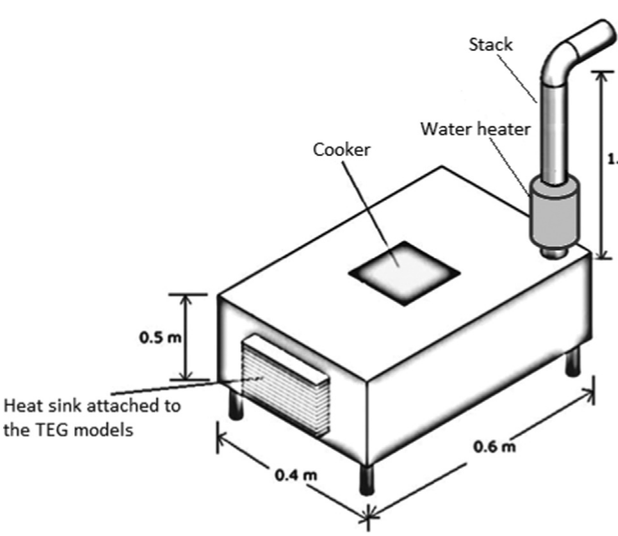


**Fig. 1.** 3D view of the JUST stove.

## 2. The experimental facility

### 2.1. A brief outlook of thermoelectricity (TE)

The first TE stove application [11] was developed by the Royal Institute of Technology in Sweden in 1990. The application was done using wood burning stove in rural areas of the country. Two high power thermoelectric generators were fitted on the stove where the temperature is highest, whereas the cold side is cooled using a heat sink together with 2.2 W fan. The best performance was in the morning with 10 W power output when the ambient temperature was low. The stove was frequently fueled, during the day time, and the power output ranged from 4 to 7 W.

Nuwayhid et al. [12] presented a study of using portion of the heat from 20 to 50 kW wood or diesel stoves. Their goal was to generate up to 100 W electric power. In the first prototype, they started using Peltier model operated on the power generation mode. The output power of this model was very low (1 W) manly because of the low temperature difference and the use of Peltier model which is made for cooling not for power generation. In their second prototype [13] they used three power generation models. The models were cooled by natural convection using a heat sink. They got a maximum output power of 4.2 W per model and they showed that the use of multiple models with a single heat sink tends to reduce the total output power. They also used heat pipes as the heat sink and they got maximum power of 3.4 W [14]. 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 got an output power of 2.4 W at a temperature difference of 150 °C. Thermo economic analysis showed that the payback period is very short. A brief table shows the power produced from many thermoelectric stove models. Their cooling methods will be shown in Section 5.

### 2.2. The experimental set-up

This stove has an improved combustor aerodynamic design and contains 12 TEG modules for electricity generation, in addition to cooker with specially-designed fins, water heater compact inner surfaces. It has a compact outside surface, enough for space heating (Fig. 1).

The heat from the combustion gases was partially recovered by installing fins on both the hot side of the TEG and the cooker. These fins act as a store of energy and they guide the combustion products along the required path from the combustion chamber, base of the TEG, fins of the cooker, then water heater towards the exit stack.

To maintain the design healthy, this stove is designed so that the user is not exposed to exhaust gases at all. Three types of fuel namely: wood, animal (horse) dung (manure) and peat, were tested. They represent the fuels which are the most available and commonly used in the remote areas around the world.

The output power of the TEG strongly depends on the temperature difference between the hot and cold sides of the model. It was obvious that the use of water as a cooling medium gives the highest power because of the higher thermal conductivity of water and the cold side temperature of the model will not exceed the boiling temperature of

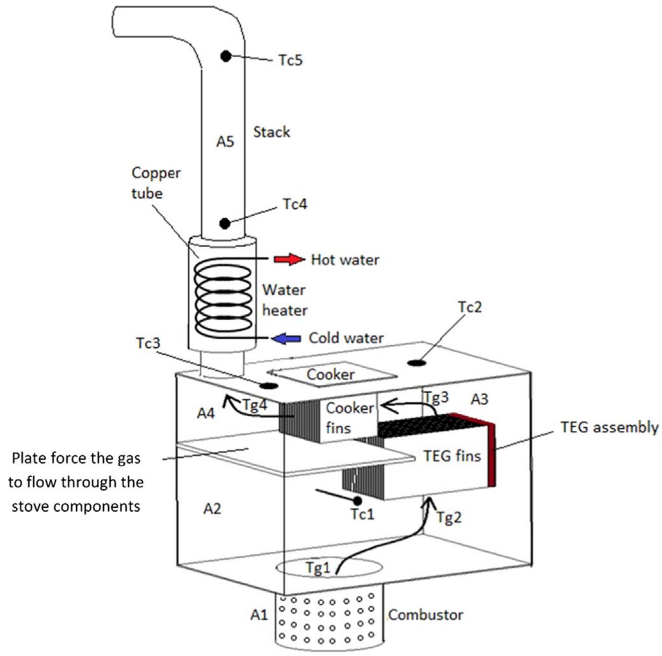


**Fig. 2.** Detailed sub-components of the stove.

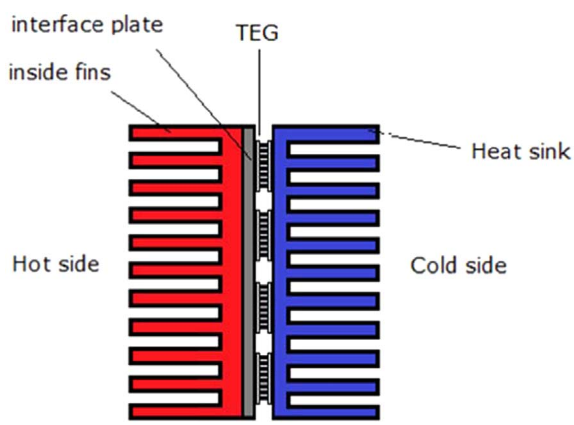


**Fig. 3.** Top view of the TEG assembly.

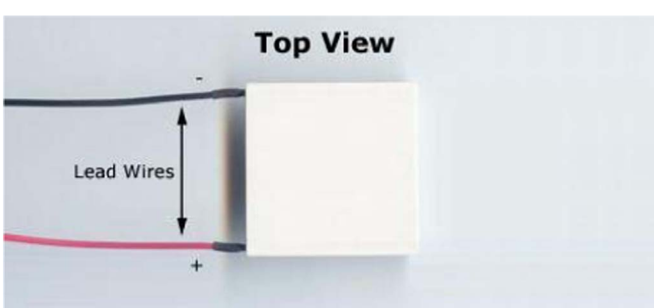


**Fig. 4.** Side view of the TEG module.

water. This allows us to elevate the hot side temperature as much as the model can take (Fig. 2).

where

$T_{g1}$: gas temperature at position 1
$T_{g2}$: gas temperature at position 2
$T_{g3}$: gas temperature at position 3
$T_{g4}$: gas temperature at position 4
$T_{c1}$: thermocouple at position 1

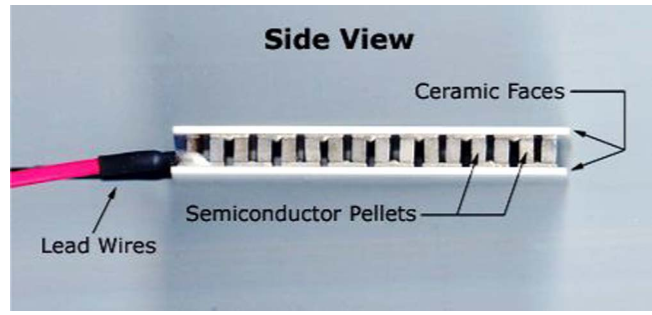


**Fig. 5.** Side view of the TEG module.

**Table 1**
TEG Module characteristics.

| Model characteristics | Symbol | Value | Unit |
|---|---|---|---|
| Maximum power | P | 3.7 | W |
| Load resistance | $R_l$ | 6.8 | Ω |
| Internal resistance | $R_i$ | 6.8 | Ω |
| Number of semiconducting pairs | N | 12 | |
| Thermal conductance | $U_{pn}$ | 0.85 | K/W |
| Size of the TEG module | | 40×40×4 | mm |

$T_{c2}$: thermocouple at position 2
$T_{c3}$: thermocouple at position 3
$T_{c4}$: thermocouple at position 4
$T_{c5}$: thermocouple at position 5
A1: combustor zone
A2: after combustor zone
A3: after TEG fins zone
A4: after cooker zone
A5: stack

*Thermoelectric generator module*: The TEG models are sandwiched between the inside fins and the heat sink as shown below (Figs. 3–5) and the characteristics of the TEG module are presented in Table 1.

**Table 2**
Characteristics of the three fuels used in the experiment.

| Property | Fuel | | |
|---|---|---|---|
| | Wood | Peat | Manure (horses) |
| Moisture content (%) | 15% | 20% | 30% |
| Ash (%) | Trace | 4% | 11% |
| Theoretical air - fuel ratio | 5.1 | 5.39 | 5.38 |
| Net Calorific value (kJ/kg) | 14,350 | 14,500 | 10,600 |
| Initial weight (kg) | 1.6 | 1.65 | 1.2 |
| Final weight (kg) | 0.1 | 0.205 | 0.233 |
| Time taken to burn it (min) | 71 | 76 | 66 |
| Ambient temperature (°C) | 17 | 17 | 17 |
| Chemical composition | Carbon (42.5%) Hydrogen (5.1%) Nitrogen and Sulfur (0.9%) Oxygen (36.6%) | Carbon (43.7%) Hydrogen (4.2%) Nitrogen and Sulfur (1.5%) Oxygen (26.6%) | Cellulose (37.8%) Hemicellulose (32.4%) Lignin (19.6%) |

## 3. Experimental procedure

The experiment is carried out on three types of fuels namely, wood, peat, and manure (horses), due to their availability in deprived regions. They can be used with and no much further treatment, with the following characteristics (Table 2):

1. The measurements of temperature along different positions of the stove were taken using type-K thermocouples at different times in order to compare it with the theoretical data.
2. The time and the initial and final weight of the fuel were recorded in order to determine the mass flow rate of fuel.
3. On the TEG assembly, two thermocouples are installed exactly at the hot and cold side of the TEG model and the measurements were taken for $T_H$, $T_c$ and $V_{oc}$.
4. All electrical quantities are measured using digital multi meter (DMM)
5. All temperature measurements were taken using a type-K thermocouple digital reader.

### 3.1. Sample calculation using wood, peat and manure

1. Rate of Fuel Consumption

   The rate of Fuel Consumption 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

   Time interval=71 min

$$\dot{m}_f = \frac{1.6 - 0.1}{71*60} = 3.52*10^{-4} \text{ kg/s}$$

2. Seebeck coefficient

$$S_{pn} = \frac{V_{oc}}{N(T_H - T_C)}$$

For wood;

Average $V_{oc}$=12.48 V Average $\Delta T$=19 K.

N=12

$$S_{pn} = \frac{12.48}{19.06*12} = 0.054 \text{ V/K}$$

For peat, $S_{pn}$=0.054 V/K

For manure, $S_{pn}$=0. 047 V/K

Maximum power

$$I = V_{oc}/(R_i + R_L)$$

$$V_{oc} = S_{pn}(T_H - T_c)$$

$$P_{max} = I^2 R_L$$

where

$R_i$=6.8 Ω

$R_L$=6.8 Ω for maximum power

$$I = V_{oc}/(R_i + R_L) = \frac{12.48}{13.6} = 0.91 \text{ A}$$

$$P_{max} = I^2 R_L = 0.91^2 * 6.8 = 5.7 \text{ W}, \quad \text{for wood}$$

$P_{max}$=6.6 W, for peat

$P_{max}$=1.8 W, for manure

## 4. Discussion of results

In general biomass fuel burning goes under three stages (all three stages can be present at the same time) (Fig. 6).

Stage 1: The fuel is heated to evaporate and drive off the moisture.
Stage 2: The fuel starts to break down chemically and the volatile matter is vaporized. The vapor contains 50–60% of the heat value of the fuel. This vapor has to be heated to 600 °C to reach the ignition temperature, hence achieving self-supported flame. If not, smoke may be generated thus, forming a plume that envelops the heat exchange surfaces and chimney with creosote.
Stage 3: Once the volatile matter is released, the remaining material (charcoal) burns at temperatures above 800 °C.

The gas temperatures are measured at different positions in the stove and at different times for the fuels sources (wood, peat and manure) as shown in (Fig. 2).

Figs. 7–12 show gas temperature after different times of burning in five positions in the stove namely: position 1 (before the TEG fins), position 2 (after the TEG fins or before the cooker), position 3 (after the cooker or before the water heater), position 4 (after the water heater) and position 5 (end of the stack). However, the temperature profiles for the three fuel sources decrease as the position change. The causes of this decrease are heat lost through the walls as follows: between positions 1 and 2; due to heat absorbed by the TEG fins, from position 2 to 3; the heat absorbed by the cooker fins, position 3–4; heat absorbed by the water heater coils.

Fig. 7 shows variation of temperatures in the 5 positions after 10 min of burning. The highest temperature is found to be for wood at position 1 with a value of 600 °C followed by the peat with value of 500 °C and finally the manure with 177 °C.

Fig. 8 shows the variation of temperature profile after 20 min of burning. It illustrates that peat has the highest temperature at the entry area of the TEG fins followed by manure then wood with temperature of (365, 330 and 260 °C, respectively). In the contrary, wood has the highest temperature value followed by peat then manure at position 2.

Fig. 9 shows the temperature profile after 30 min. Peat has the highest temperature followed by manure then wood. At position 3, wood outruns manure and gives temperature of 133 °C while manure has 110 °C.

Fig. 10 shows the measured temperatures after 40 min. Peat has the highest value followed by wood then manure.

Figs. 11 and 12 show the temperature profiles after 50 and 60 min, respectively. The temperature of the wood doesn't change much at position 1 and 2.

Fig. 13 shows the exit temperature of the combustor for the three fuels from the initial ignition until 60 min of burning. The highest temperature for the wood would occur at 10 min with a temperature value of 600 °C. While the peat has the highest value at the same time with 520 °C. However, the highest temperature for manure is at 25 min

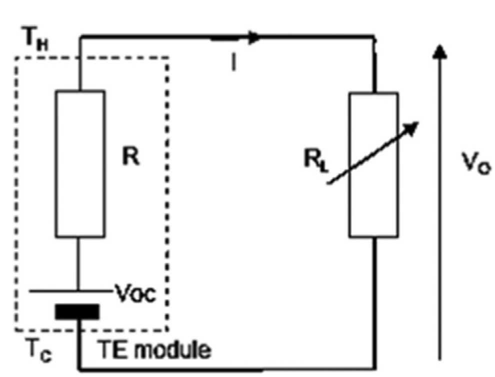


**Fig. 6.** Electric circuit shows the TEG module.

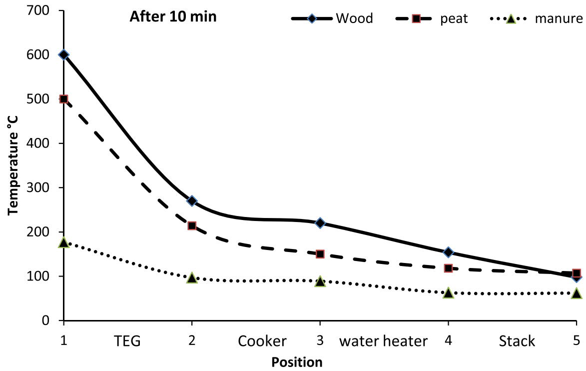


**Fig. 7.** Gas temperature profile along the path in the stove after 10 min.

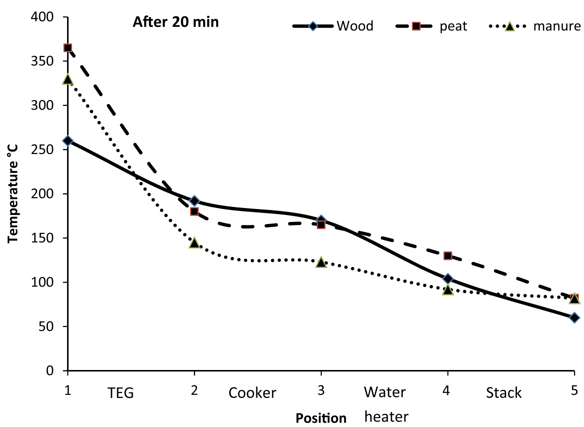


**Fig. 8.** Gas temperature profile along the path in the stove after 20 min.

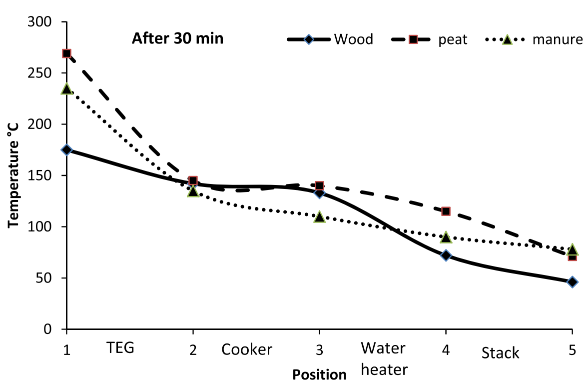


**Fig. 9.** Gas temperature profile along the path in the stove after 30 min.

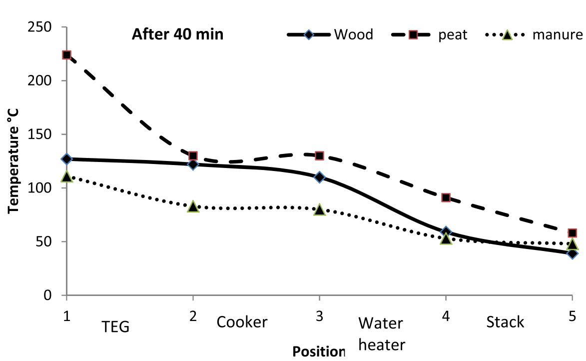


**Fig. 10.** Gas temperature profile along the path of the stove after 40 min.

with a value equals to 365 °C. It is obvious that wood has the highest temperature; this is due to the higher burning rate and lower moisture content in comparison with peat and manure. Although the peat has a

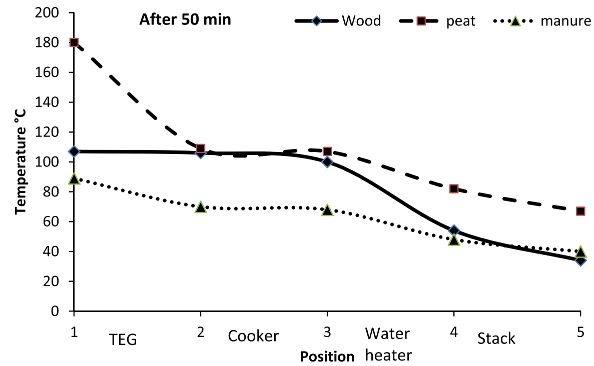


**Fig. 11.** Gas temperature profile along the path of the stove after 50 min.

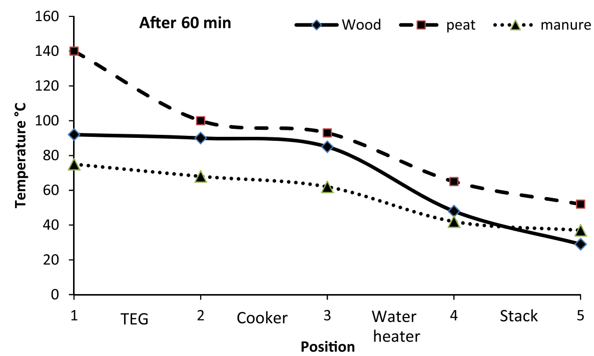


**Fig. 12.** Gas temperature profile along the path of the stove after 60 min.

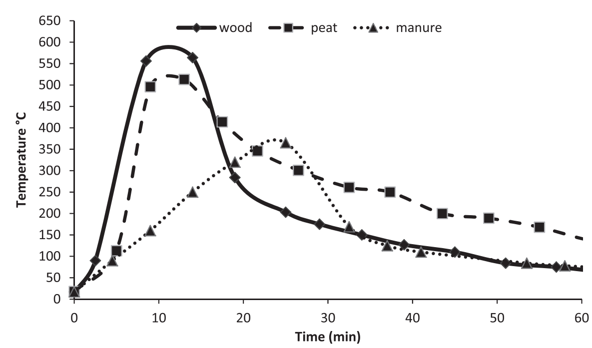


**Fig. 13.** Variation of combustor exit temperature (Tg1) with time.

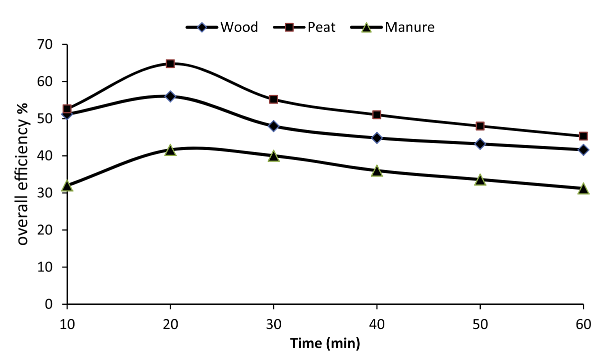


**Fig. 14.** Overall efficiency with time for different fuels.

higher calorific value, it has a lower burning rate. Therefore, its temperature at the steady flow may be higher than wood.

Fig. 14 shows the overall efficiency (Total heat absorbed by TEG fins, cooking fins and water heater coils and lost by the stove walls and stack over the heat input of the fuel). Peat shows the optimum thermal efficiency at 20 min with 64.8% followed by the wood with 56% then the manure with 41.6%. The peat produces the higher efficiency due to

**Table 3**
TEG measurements using wood as fuel.

| Time | $T_H$ | $T_C$ | ΔT | $V_{oc}$ | $P_{max}$ |
|---|---|---|---|---|---|
| 0 | 17 | 17 | 0 | 0 | 0 |
| 7.5 | 44 | 28 | 16 | 9 | 2.97 |
| 11 | 69 | 41 | 28 | 14.1 | 7.30 |
| 16.5 | 109 | 68 | 41 | 21.4 | 16.83 |
| 21.5 | 116 | 81 | 35 | 18.5 | 12.58 |
| 27.5 | 119 | 95 | 24 | 16 | 9.41 |
| 31.5 | 119 | 98 | 21 | 14.8 | 8.05 |
| 37 | 117 | 99 | 18 | 13.5 | 6.70 |
| 39.66 | 115 | 98 | 17 | 12.4 | 5.65 |
| 41 | 115 | 98 | 17 | 12 | 5.29 |
| 42.5 | 114 | 98 | 16 | 11.5 | 4.86 |
| 47.5 | 110 | 96 | 14 | 10.7 | 4.20 |
| 53.5 | 105 | 93 | 12 | 9.6 | 3.38 |
| 58 | 101 | 89.5 | 11.5 | 9 | 2.97 |
| 65.5 | 94 | 85.5 | 8.5 | 7.7 | 2.17 |
| 71 | 90 | 83 | 7 | 7 | 1.80 |

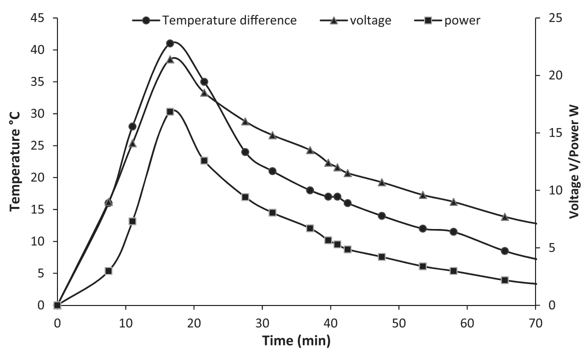


**Fig. 15.** Output voltage and power plus temperature difference vs time with wood.

**Table 4**
TEG measurements using peat as fuel.

| Time | $T_H$ | $T_C$ | ΔT | $V_{oc}$ | $P_{max}$ |
|---|---|---|---|---|---|
| 0 | 18 | 18 | 0 | 0 | 0 |
| 8 | 35 | 25 | 10 | 5.4 | 1.07 |
| 11.125 | 54 | 34 | 20 | 10.6 | 4.13 |
| 16.8 | 89 | 56 | 33 | 16.5 | 10.00 |
| 20.66 | 100 | 70 | 30 | 17 | 10.62 |
| 25.33 | 109 | 82 | 27 | 16.7 | 10.25 |
| 30.25 | 115 | 90 | 25 | 16.3 | 9.76 |
| 36.125 | 120 | 96 | 24 | 15.85 | 9.23 |
| 39.66 | 121 | 99 | 22 | 15.5 | 8.83 |
| 47.5 | 122 | 101 | 21 | 14.5 | 7.72 |
| 53 | 120 | 101 | 19 | 13.5 | 6.70 |
| 59 | 118 | 100 | 18 | 12.5 | 5.74 |
| 65 | 113 | 98 | 15 | 11.6 | 4.94 |
| 70.5 | 109 | 95 | 14 | 10.7 | 4.20 |

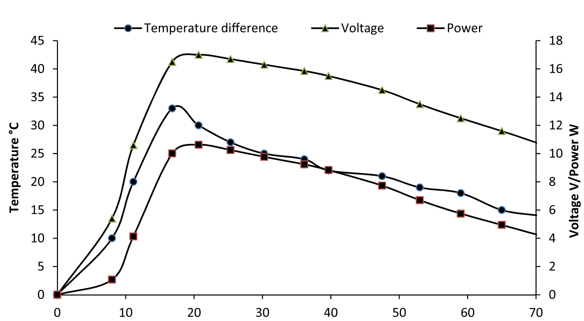


**Fig. 16.** Output voltage and power plus temperature difference vs time with peat.

**Table 5**
TEG measurements using manure as fuel.

| Time | $T_H$ | $T_C$ | ΔT | $V_{oc}$ | $P_{max}$ |
|---|---|---|---|---|---|
| 0 | 17 | 17 | 0 | 0 | 0 |
| 8.16 | 38 | 27 | 11 | 5.12 | 0.96 |
| 22.33 | 61 | 46 | 15 | 8 | 2.35 |
| 32 | 78 | 59 | 19 | 9.9 | 3.60 |
| 35.5 | 79 | 62 | 17 | 9.1 | 3.04 |
| 39.75 | 79 | 64 | 15 | 8.45 | 2.62 |
| 46 | 78 | 66 | 12 | 7.5 | 2.06 |
| 50.83 | 76 | 65 | 11 | 7.1 | 1.85 |
| 56 | 74 | 63 | 11 | 6.6 | 1.60 |
| 60.5 | 72 | 62 | 10 | 6 | 1.32 |
| 65.66 | 70 | 61 | 9 | 5.7 | 1.19 |
| 70 | 69 | 60 | 9 | 5.7 | 1.19 |

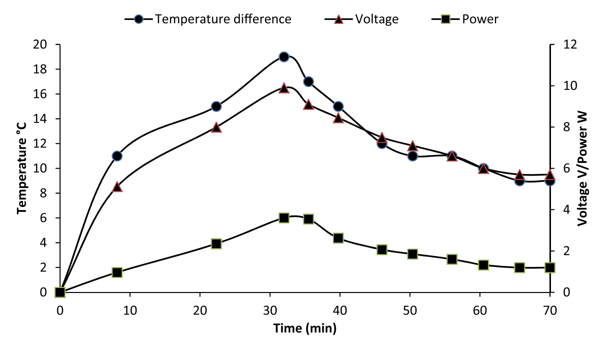


**Fig. 17.** Output voltage and power plus temperature difference vs time with manure.

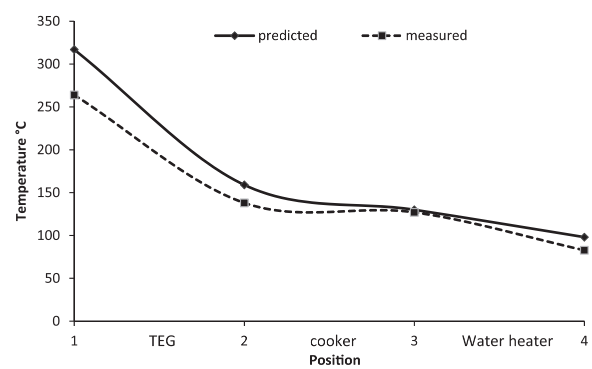


**Fig. 18.** Comparison of predicted and measured temperature profile along the stove using wood.

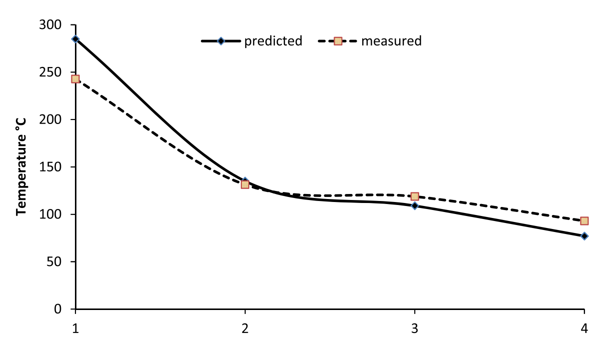


**Fig. 19.** Comparison of predicted and measured temperature profile along the stove using peat.

its higher calorific value.

Table 3 shows the TEG characteristics performance variables from the beginning of burning until the fuel is totally burned. It is shown that the temperature difference, voltage ($V_{OC}$) and maximum power increases to maximum point of burning which is at 16.5 min and then

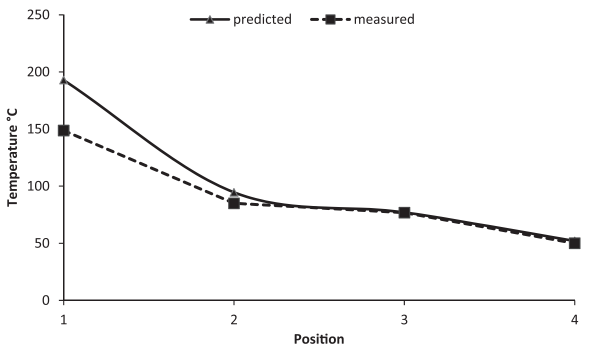


**Fig. 20.** Comparison of predicted and measured temperature profile along the stove using manure.

**Table 6**
Different types of thermoelectric stoves, their cooling mode and the output power of the TEG.

| | Authors | Cooling mode | Max. power per model |
|---|---|---|---|
| 1 | Royal Institute of Technology in Sweden [10] | Forced convection (2.2 W) | 10 W |
| 2 | Nuwayhid et al. [11] | Natural convection | 1 W |
| 3 | Nuwayhid et al. [12] | Natural convection | 4.2 W |
| 4 | Nuwayhid and Hamade [13] | Heat pipes cooling | 3.4 W |
| 5 | Champier et al. [15] | Water cooling | 6 W |
| 6 | Champier et al. [16] | Water cooling | 9.5 W |
| 7 | Lertsatitthanakorn [17] | Natural convection | 2.4 W |
| 8 | Mastbergen and Wilson [18] | Forced convection (1 W) | 4 W |
| 9 | Raman et al. [19] | Forced convection (0.83 W) | 4.5 W |
| 10 | BioLite [20] | Forced convection (1 W) | 1–2 W |
| 11 | O'Shaughnessy et al. [21] | Forced convection (0.5 W) | 3 W h/day |
| 12 | JUST stove (Wood) | Natural convection | 5.7 W |

**Table 7**
Total components cost.

| Item | Price $ |
|---|---|
| Stove construction | |
| Stove body | $250 |
| Heat sink | $25 |
| Thermoelectric generator modules | $320 |
| Battery | $30 |
| Water heater | |
| Cupper tubes | $25 |
| stack | $10 |
| Water tank | $20 |
| Pipes and fitting | $15 |
| Miscellaneous | |
| Heat sink compound | $20 |
| Safety tools | $32 |
| Measuring instruments | $150 |
| Transportation | $30 |
| Total | $972 |

decrease as shown in Fig. 15.

Table 4 and Fig. 16 show the performance of the TEG fins for peat. The maximum point is at time 20.66 min with maximum power of 10.25 W.

Table 5 and Fig. 17 show the performance measurements of manure as fuel with maximum power occurring after 32 min of burning with a value equals to 3.6 W.

The wood produces the highest output power due to its higher temperature but it decays faster than the peat.

Figs. 18–20 compare the predicted temperature profile with the measured one for wood, peat and manure, respectively. The predicted values are slightly higher than the measured ones, due to the error associated with the carbon deposits on the junction of the thermocouple. This is in addition to the human error when taking the measurements.

Finally, it is advantageous to describe briefly the development of flame with different fuels:

1) After 10 min of combustion, the wood reaches the highest gas temperature (600 °C) because it has less moisture content and higher heat release rate than other fuels.
2) After 20 min of combustion, the peat and manure reach higher temperatures than wood. In the first 10 min, the peat and manure evaporate the moisture and so the temperature was relatively lower.

## 5. Comparison among different types of thermoelectric stoves

Comparison among different types of thermoelectric stoves based on the power produced and cooling mode is presented in Table 6. It shows that the JUST stove performance is within that of all the documented stoves. They have a wide range of performance due to the difference in design particulars and operating conditions.

## 6. Economics of the stove

The following table shows the manufacturing cost of the JUST stove Table 7

The price is relatively high. However, the more units are produced, the cheaper will be the price per stove, due to the lower production cost of the subcomponents including the TEG. Moreover, the price will further decrease as technology advances. It is reported that the cost of the TEG is 22.75 $/unit [15]. However, JUST stove's TEG cost is 27 $/unit. The relative cost difference for the TEGs is 32.9%. The major technology modification can be done on the TEGs, thus improving the characteristics especially performance by increasing the power augmented. Consequently as well as the higher quantity of TEGs produced the cost decreases.

## 7. Conclusions

1. The peat showed the best performance in terms of the rate of fuel consumption.
2. The output power of the TEG strongly depends on the temperature difference between the hot and cold sides of the model. The temperature difference of the TEG model reaches its maximum temperature (43 °C) using wood but it decays faster than peat.
3. The maximum overall efficiency (65%) is obtained when using peat because of its high heating value.

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