Applied Energy 156 (2015) 566–576

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Performance analysis of a prototype small scale electricity-producing biomass cooking stove

S.M. O'Shaughnessy [a], M.J. Deasy [a], J.V. Doyle [b], A.J. Robinson [a,*]

[a] Department of Mechanical & Manufacturing Engineering, Parsons Building, Trinity College Dublin, Ireland
[b] Concern Universal, Plot No. LK 367, Michuru Road, Blantyre, Malawi

HIGHLIGHTS

- Five thermoelectric generating devices have been integrated with a cooking stove.
- The stoves were equipped with temperature and power data logging equipment.
- Power generation performance was analysed over the first 80 days of a field trial.
- Users were able to charge mobile phones, lights and radios from the generators.
- The field trial has informed a redesign of the power circuitry and the generator.

ARTICLE INFO

Article history:
Received 4 March 2015
Received in revised form 16 July 2015
Accepted 20 July 2015

Keywords:
Biomass
Cooking stove
Thermoelectric
Electricity generation
Phone charging
Malawi

ABSTRACT

An electrical generator has been integrated with a locally produced, biomass-fed clay cooking stove in rural Malawi. The generator produces small amounts of electricity based on the thermoelectric effect. Five demonstrator stoves were deployed into a rural community in the Balaka district for up to 6 months. This study investigates the power generation performance of the devices over the first 80 days of the field trial. It was determined that the users were able to charge mobile phones, lights and radios from the generator stoves. The power generating performance of the stoves deteriorated slightly over the 80 day period. The was due to the effects of thermal cycling on the generator system as a whole which caused eventual drying out of the thermal paste and a loosening of the clamping nuts which reduces clamping pressure and power output. One stove failed due to a mechanical problem. It was found that the power produced significantly exceeded the power consumed in most cases, which indicates an over-supply. It appears that 3 W h is sufficient to meet the average daily electrical power requirements for the participants in this study. The data obtained from the field trial has been used to inform a redesign of the device for a second field trial.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

In their 2010 Energy Poverty report the OECD/IEA estimated that investment of $36 billion per annum was necessary to ensure that every citizen in the world benefits from access to electricity and clean cooking facilities by 2030 [1]. The report also stated that new dedicated policies were required if the conditions for the lives of billions of people are to improve. However, to make key decisions regarding the welfare of their citizens and help refine policies over time, policy-makers rely on quantitative information and analysis [1].

Globally, approximately 1.4 billion people lack access to electricity with the vast majority living in rural areas. Furthermore, the number of people depending on the traditional use of biomass is projected to reach 2.8 billion by 2030 [1]. The problem is particularly evident in sub-Saharan Africa where the electrification level is only 31% and 80% of people burn biomass as their primary source of household energy [1].

Thermoelectric generators have recently been investigated as a method of electricity generation from biomass burning. The use of thermoelectric generators for waste heat to electricity conversion is not new, but perhaps is only now becoming more evident in everyday applications. For example, Codecasa et al. [2,3] recently developed a 5 W, 12 V TEG system with the goal of powering an autonomous gas heater for commercial outdoor use. To date, TEGs have been predominantly limited to low power demand

* Corresponding author. Tel.: +353 1 896 3919.
E-mail address: arobins@tcd.ie (A.J. Robinson).

http://dx.doi.org/10.1016/j.apenergy.2015.07.064
0306-2619/© 2015 Elsevier Ltd. All rights reserved.

Nomenclature

Symbol	Description (Unit)		
L	length of thermo-element (m)	T_h	module hot side temperature (K)
L_c	contact layer thickness (m)	T_c	module cold side temperature (K)
P_{elec}	electrical power (W)	ΔT_{TEG}	module temperature difference (K)
P_{TEG}	power generated by the TEG (W)	ΔT_{actual}	actual TEG temp. difference (K)
P_{USB}	power consumed by user via USB (W)	$\Delta T_{apparent}$	Apparent TEG temp. difference (K)
R_L	load resistance (Ω)	W_{TEG}	power generated by the TEG (W h)
R_{TEG}	TEG internal resistance (Ω)	W_{USB}	power consumed by user via USB (W h)
R_{TH}	thermal resistance (°C/W)	α	seebeck coefficient (V/K)
		α_{eff}	effective seebeck coefficient (V/K)

systems, but larger scale studies have also been carried out, such as those by Doloszeski and Schmidt [4] who investigated the use of a large thermoelectric module in combination with a fluidised bed combustor to obtain up to 450 W of electrical power.

Much of the research investigating the potential for TEGs in low temperature waste heat harvesting has been laboratory based, such as studies by [5–7]. Although the concept of integrating thermoelectric generators with cooking stoves has been investigated, many studies have focussed on optimising the TEG output under fixed parameters [8]. Although this method does offer valuable information on the performance of the generator, the test conditions are typically strictly controlled and the heat source in many cases is derived from an electrical power supply rather than the more erratic conditions encountered in a live fire.

Of those researchers who experimentally investigated TEG integration into a working stove, Killander and Bass [9] were some of the earliest. In their study in an isolated home in northern Sweden, a thermoelectric generator was connected to a wood-fed stove. Using two Hi-Z HZ20 modules cooled by a 12 V, 2.2 W fan, their prototype was capable of producing up to 10 W in the cold mornings, with 4–7 W produced as the house became warmer during the day. The output voltage from the TEGs was boosted to 13.5 V by a DC/DC converter and the generated power was sufficient to operate the cooling fan and charge four 6 V batteries. These batteries were connected in series/parallel to maintain a 12 V output to provide some electric light and supply some television during the night.

Sawyer et al. [10] designed a thermoelectric module coupled with a Haitian cooking stove. The primary intention was to increase the efficiency of the stove by rerouting the TEG cooling air to the combustion chamber. The minimum requirement of the generator was to power its own cooling fan. The authors also intended to charge a battery pack which would allow the fan to run at start-up without TEG power, and to charge a secondary battery pack that would be able to power devices connected via USB. A Taihuaxing module TEP-1264-1.5 was used which could produce up to 4 W at a temperature difference of 200 °C. It was discovered that halving the flow rate of air into the combustion chamber had minimal effect on the time to boil 2 l of water, but noticeably affected the cooling of the TEG. Indeed, the design relied on the fan running at the maximum flow rate at all times. In their experiments the desired temperature differential of 200 °C could not be achieved due to rising cold side temperatures. The authors determined that the main issue with the system was how the limited power provided by the thermoelectric module was budgeted between the components and loads.

Champier et al. [11,12] investigated using the exhaust gases stream from an energy efficient mud cooking stove as the heat source for a thermoelectric generator. An experimental rig was setup initially using a 2.2 kW butane gas burner. Using four bismuth telluride thermoelectric modules (Taihuaxing Co., Ltd. TEP1-12656-0.8, max. 10.5 W at matched load) the authors obtained between 1.7 W and 2.3 W per module at an approximate module temperature difference of 160 °C and a total of 7 W was generated. Citing the clamping pressure as one of the main reasons for the low power output, the authors made improvements to the generator design in what was called the "TEGBois II" and included a fan to replicate the gas temperatures and flow speeds in the stove. With a moving airstream at approximately 400 °C and maximum power point optimisation of the DC–DC power conversion [13], the authors obtained much improved power output and an energy efficiency for the electrical conversion of over 90%.

Goudarzi et al. [14] designed a multifunction device capable of producing a considerable amount of electricity as well as hot water. The prototype stove was equipped with baffles and a post-combustion chamber which ensured more complete burning of the exhaust gases by returning them to the hottest part of the firebox. At low stove temperatures, combustion was aided by a 1 W fan to aerate the fire. 21 thermoelectric modules (TEP1-12656-0.6) were used, each one connected by its hot side to a 50 mm-long aluminium piece which in turn was attached to the stove body. In this way the upper temperature limit of the TEGs was not exceeded. The modules were divided into seven groups of three, each connected electrically in series. Each TEG was cooled via a water-filled aluminium block, through which the water flow rate could be adjusted. The authors tested in an open environment and experimented with different fuel consumption rates, ultimately producing an average of 7.9 W for each module when charging with 9 kg of firewood per hour.

Raman et al. [15] described the development, design and performance analysis of a forced draft clean combustion cookstove powered by a single thermoelectric module capable of producing 5 W at matched load. The power produced by the TEG was to power the blower to provide a clean combustion and reduce indoor air pollution. Since the authors obtained a maximum of 4.5 W from the TEG and less than 1 W was needed to power the blower, the remaining power was used for mobile phone charging and LED lighting.

Recently, the present authors described the design, laboratory testing, and field trial testing of an electricity producing cooking stove [16,17] along with the development of appropriate charge control circuitry [18]. Results are discussed in the context of laboratory tests with the view of verifying the efficacy of the technology and provide a context within which actual use in field trials can be assessed. Ref. [17] outlined the deployment and preliminary results of a field trial, whereby five stoves with TEG generators and five without were equipped with data logging equipment and use behaviour was monitored for 80 days. This paper focussed primarily on behavioural aspects of the field trial participants including energy supply and demand. Here it was found that the technology was used as intended and provided sufficient, if not an abundance of electrical energy that was used by the participants to charge phones and LED lanterns for the duration of the field trial.

Download English Version:

https://daneshyari.com/en/article/6686310

Download Persian Version:

https://daneshyari.com/article/6686310

Daneshyari.com