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Thermoelectric stoves for poor deprived regions – A review

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ABSTRACT

Thermoelectric generator (TEG) is a device that harvests waste heat and converts some of it to a useful power enough to run small electric devices. Since biomass cooking stoves are widely used in underdeveloped countries where there is no access to electricity, it is very appropriate to use TEG by attaching it to the side of the stove. This will improve the utility and efficiency of the original stove.

Efficiency of operation with biomass fuels including wood, peat and manure has been studied along with the economics of the stoves.

Moreover, this work studied the serious consequences of using biomass fuels on health and environment if not properly burned. This review refers to JUST multi-purpose stove which has an improved combustor aerodynamic design and unique heat transfer arrangement.

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 using clean fuels [1], utilization of waste heat [2–6] and adopting different configurations [7–9], where resources and environment are conserved.

More than 20% of the world's population in the developing countries is still living without electricity [10]. Providing a minimum amount of electricity that covers the basic needs to this large population can be very expensive using power plants. Fitting TEG to the stove is 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 that 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 the semiconductors when they form a complete loop. This is fully illustrated in Fig. 1.

The major advantages of using thermoelectric generators are:

a) They do not requires additional energy from the stove,
b) They do not require electricity,
c) They require almost no maintenance since there are no moving parts,
d) They work continuously in any weather.
e) They do not require large battery system.

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% [10] 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.

The main objectives of this work are to review briefly the different constructions of stoves in under developed countries including thermal stoves besides their counter parts of thermoelectric stoves. Moreover, efficiency, economic analysis and health issues are carried out.

2. Thermoelectric stoves

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 using 20–50 kW wood or diesel stoves. Their goal was to generate up to 100 W electric power. In their first trial they used a Peltier model to generate electricity. The power output was very low (1 w) for two reasons, firstly the low temperature difference along the model sides and secondly the use of Peltier model which is made for cooling not for electricity generation.

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Nomenclature

CO	Carbon monoxide
CPU	Central processing unit
DC	Direct current
DNA	Deoxyribonucleic acid
HCHO	Formaldehyde
LED	Light emitting diodes
LPG	Liquid petroleum gas
NO_2	Nitrogen dioxide
PAH	Polycyclic aromatic hydrocarbons
PM	Particulate matters
SO_2	Sulfur dioxide
TEG	Thermoelectric generator
TSP	Total suspended particulates
VOCs	Volatile organic compounds

In their second trial [13] they used three power generation models. They were cooled using heat sink. They got a maximum output power of 4.2 W per model and they showed that output power has been significantly improved.

They also used heat pipes as the heat sink and they got maximum power of 3.4 W [14]. Champier et al. [15] studied the use of thermoelectric generator to produce electric power to run a fan to ensure complete combustion and for light, in the first prototype. 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 [16] they used a different thermoelectric model that works at higher temperatures.. 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 achieved a maximum output power of 9.5 W 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 got an output power of 2.4 W at a temperature difference of 150 °C. Thermo economic analysis showed a very short payback period.

Mastbergen and Wilson [18] presented a prototype of TEG cooled by a 1 W fan. They generated a net output power of 4 W which was enough to light an array of high intensity LEDs. Raman P et al. [19] installed a thermoelectric generator to provide power required to operate a DC blower which will be used to ensure a complete combustion. The DC blower is arranged in a way that the air flows directly on the heat sink connected to the thermoelectric model. The output power of the thermoelectric generator was 4.5 W at temperature difference of 240 °C.

BioLite [20], produced lightweight stoves which focused on burning wood hence, generating electricity using TEG for charging portable electronic devices. The Home Stove and the Camp Stove are two makes of this stove as designed by BioLite.

O'Shaughnessy et al. [21] performed 80- day field trial testing on an improved cooking stove adapted with TEG for electricity production. They cooled their TEG model with a CPU heat sink modified with low power DC motor capable of operating a the fan with voltage as low as 0.3 V. This not only reduced the amount of power (0.5 W) required from the TEG to drive the fan but also initiated the cooling immediately once the fire is lit. The data obtained varies among the tested stoves but they were able to provide 3 Wh a day which was enough energy to serve the electrical appliances for the participant families.

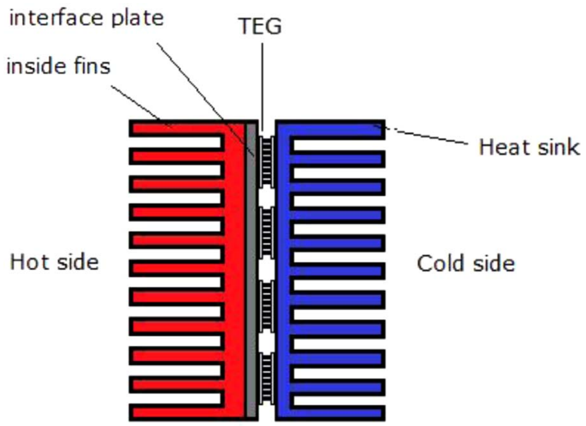

Fig. 1. TEG assembly showing the principle of Seebeck effect.

Table 1 depicts the list of references which covered the cooling mode in this work along with the power output.

There are other issues which cannot be ignored when designing the stove. These issues are related to the fuel used and its effect on the environment and health.

3. Fuel and performance

Availability of fuel and the income of the family are the main factors which determine the selection of fuel for cooking. Rehfuess et al. [22] show that the developing countries use a huge amount of biomass fuel. It reaches about77% in sub-Saharan Africa, and 74% in the Western Pacific and Southeast Asia. A greater fraction of households using biomass fuels in rural areas. In Table 2, The main pollutants emanating from the combustion of biomass are compared against those from coal, NG and LPG [23].

It is important to provide improved cooking technologies that will improve burning efficiency, reduce fuel consumption and pollutants.

Samuel Adinoyi Ayo [24] designed and built an improved wood stove providing an insulated combustion chamber and enough excess air for complete combustion. The maximum thermal efficiency was 64.4% with a minimum specific fuel consumption of 0.447 kg/kW h compared to an average thermal efficiency of 18% and higher specific fuel consumption. Cooking stoves used in Mexico have been evaluated with respect to energy performance and showed significant improvement in fuel consumption which is realized with Patsari stoves against the traditional open fire, namely 44–65%.

Raman et al. [19] installed a thermoelectric generator on a biomass

Table 1
The cooling mode and the output power of the TEG.

Authors	Cooling mode	Max. power per model
Royal Institute of Technology in Sweden [11]	Forced convection (2.2 W)	10 W
Nuwayhid et al. [12]	Natural convection	1 W
Nuwayhid et al. [13]	Natural convection	4.2 W
Nuwayhid and Hmamde [14]	Heat pipes cooling	3.4 W
Champier et al. [15]	Water cooling	6 W
Champier et al. [16]	Water cooling	9.5 W
Lertsatitthanakorn [17]	Natural convection	2.4 W
Mastbergen and Wilson [18]	Forced convection (1 W)	4 W
Raman P et al. [19]	Forced convection (0.83 W)	4.5 W
BioLite [20]	Forced convection (1 W)	1–2 W
O'Shaughnessy et al. [21]	Forced convection (0.5 W)	3 W h/day