Self – Energy Generating Cookstove

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ABSTRACT

This paper emphasizes on a sustainable way of utilizing waste thermal energy produced from the cookstove used in rural areas and converting directly to useful electrical energy. The process of converting thermal energy into electricity is achieved by using a thermoelectric generator (TEG) module. A difference in temperature on both the sides of TEG proportionally produces electricity. An appropriate TEG module is selected with reference to is temperature tolerance and various electrical parameters. The power attained from the TEG can be utilized for various purposes like running a fan to improve the efficiency of cookstove and provide sufficient air inside the combustion chamber to increase the air-fuel ratio and to achieve complete combustion, charge battery of mobile phones, run a small radio, lighting and many other applications. The fan running by a TEG serves dual purposes of cooling one side of the TEG (so that the temperature difference is maintained) and providing air for combustion of the fuel to make cooking clean without harmful emissions. The power generated from the chosen TEG is 3 Watt which powers a 3.2 Volt fan and charge batteries.

Keywords: Thermoelectric generator (TEG), cookstove, waste heat.

1. INTRODUCTION

Cooking is one of the most essential parts of daily household practices. The mode of device for cooking varies from rural to urban areas. The Rural and Urban population in India was last reported at 69.90 and 30.1 (% of total population) respectively in 2010, according to a World Bank report published in 2012. The growth rate of population in rural and urban areas was 12.18% and 31.80% respectively. About 65 % of the population in urban area use LPG as cooking fuel compared to 62.5 % of the rural household use firewood as cooking fuel. Using firewood, dung cake, crop residue etc. in traditional cookstove results in lower efficiency, high emissions of air pollutants and smoke. The emissions from the traditional cookstove are very hazardous which subsequently lead to many harmful diseases like respiratory disease, eye irritation, premature birth, death of fetus and many more. Cookstoves with a fan attached to it gives a more cleaner cooking since it increases the air-to fuel ratio and enhances combustion. Most of the rural villages are still not electrified, so to run a fan for the cookstove needs power from grid. A solution to run a fan off-grid is to integrate a thermoelectric generator and utilize the waste heat of the cookstove to directly convert it into electricity.

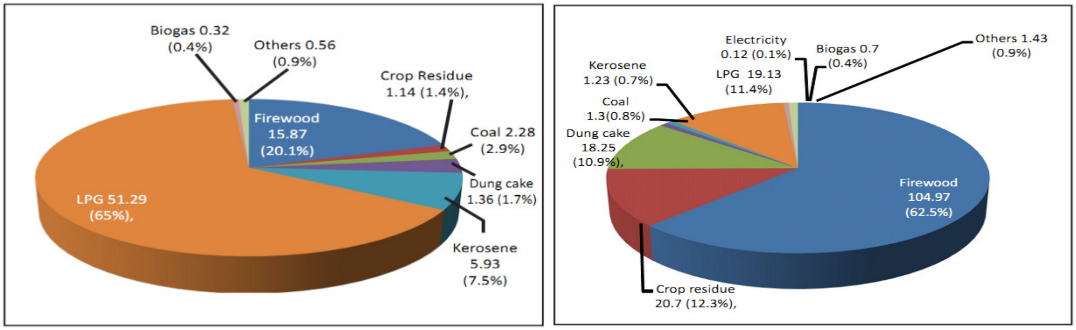


Fig 1: Use of different fuels for cooking in urban and rural India respectively from census 2011.

The principle behind TEG is to convert waste heat as heat source into electricity, which is regarded as totally green technology since the input energy is totally free of cost, and the output of the of the TEG module is of high importance due to its power generating feature and making the cookstove economically viable. On the advent of semiconductor material science the thermoelectric generation practical applications got high emphasis of conversion of waste heat into electricity. The features like reliability and ruggedness of semiconductor material that came from solid state function has made this technology more viable and useful. The advantages of TEG integrated with cookstove are that the flame heat from the cookstove serves as input to the TEG and no extra energy is required, the TEG module is incorporated in the wall of the cookstove, unlike solar panel it do not require external electric link. The module is used to charge battery and run equipments, the TEG have no moving parts hence the operation is silent, TEG is very rugged and almost maintenance free; whole module is placed indoor and no moving parts only battery needs replacement when exhausted or can be recharged with module power continuously, TEG starts working as the cookstove is set on fire irrespective of day and night, windy or rainy weather unlike solar panels. Rechargeable batteries serve the purpose and need not be oversized batteries as used in solar panels to store energy.

2. THERMOELECTRIC GENERATION

TEG Fundamentals

In 1821, Thomas J. Seebeck discovered that a potential difference could be produced by a circuit made from two dissimilar wires when one of the junctions was heated. This is called Seebeck effect. The emf is proportional to the temperature difference. The potential difference, $\mathbf{V} = \boldsymbol{\alpha}\boldsymbol{\Delta}\mathbf{T}$, where, $\mathbf{\Delta T = T_h - T_c}$ and α is the Seebeck coefficient or thermopower expressed in $\mathbf{\mu V/K}$ and the sign of α is positive if emf tends to drive an electric current through wire A from the hot to cold junction. The components of thermoelectric modules comprise of two different semiconductor materials also known as Seebeck cells. TEG exhibits Seebeck effect for conversion of heat energy into electricity as shown in fig. 2. The TEG module has many semiconductors connected electrically in series to elevate the resulting voltage and due to the temperature difference between the walls of the plate energy is captured from thermally excited electrons.

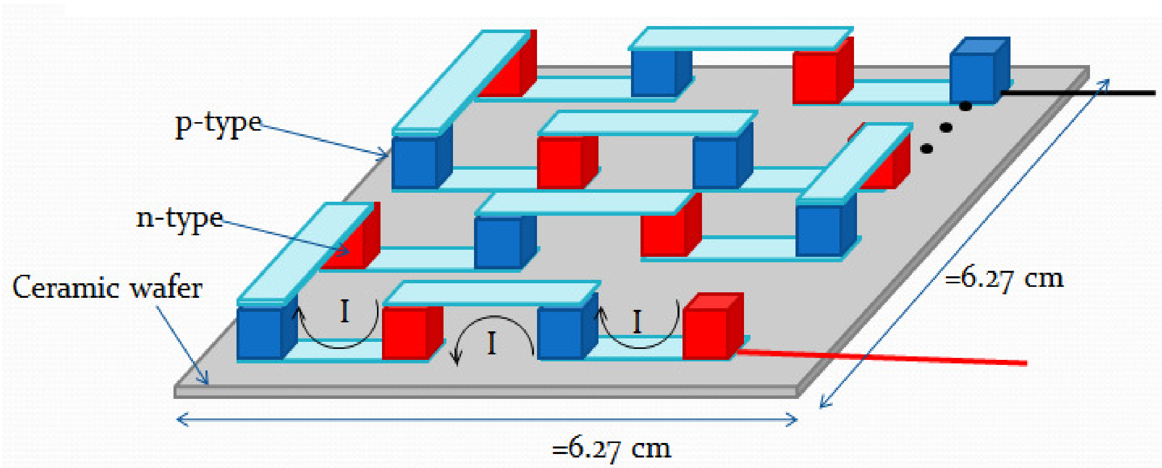


Fig. 2: Seebeck cells arrangement in a module.

The components of thermoelectric modules comprise of two different semiconductor materials also known as Seebeck cells. The legs of the n and p-semiconductors are connected thermally in parallel and electrically in series. As shown in above fig 2.Two ceramic wafers are placed in both faces of the TEG to provide insulation. Thermal grease (heat conductive paste) is applied to attach the wafers. Thermal Grease has higher thermal conductivity and is considered to be of a higher quality and include high performance levels during long periods of time, the ability to withstand higher temperatures and lower vaporization potential. The function of the semiconductor device is that when heat flows through the module, the N-type material have highly negative charges i.e. excess of electrons and the P-type material has more positively charged ions i.e. excess of holes which results in electric flow of current. Most of them are alloys based on bismuth integrated with materials like tellurium, antimony and selenium which are generally operated in low temperatures to around 450K to 1300 K. The commercially available TEG for ambient air application and with reasonable price, is Bismuth Telluride $\mathbf{Bi_2Te_3}$. The efficiency of TEG is the function of temperature; it is called 'goodness factor' or 'figure-of-merit' of the thermocouple material $\mathbf{Z} =$

$\frac{\alpha^2\sigma}{k}$, where Z is the electrical power factor, α, the Seebeck coefficient, σ the electrical conductivity and k is the total thermal conductivity. The FOM is considered as a dimensionless form, ZT where T is absolute temperature. The highest FOM for bismuth tellurium fabricated from p- and n-thermocouple is recorded around $2.0 \times 10^{-3}\ K^{-1}$.

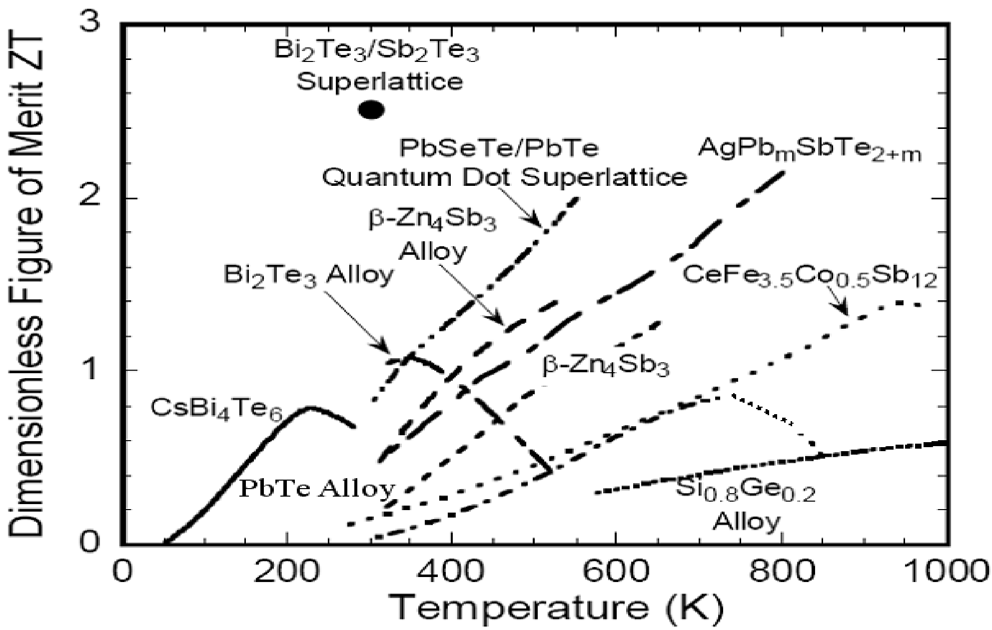


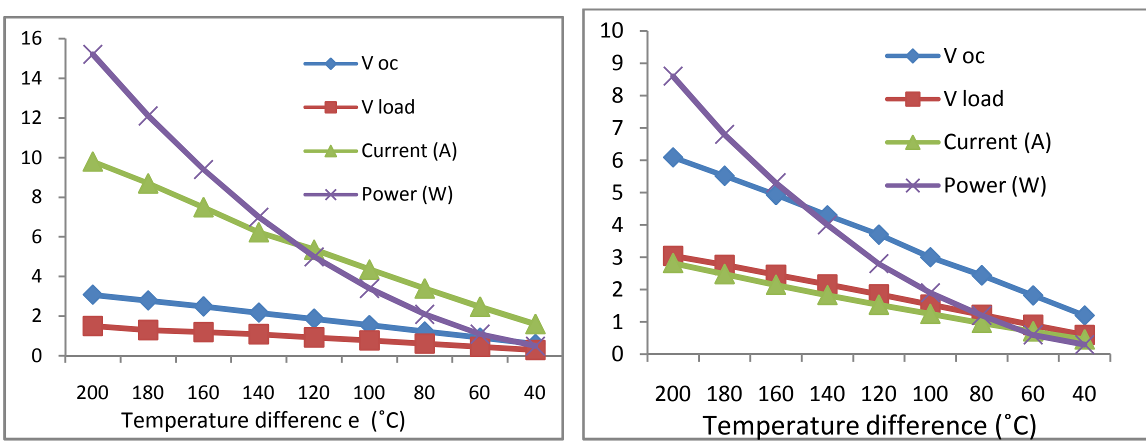
Fig. 3: Figure-of-Merit of a selection of materials [9]

3. RESULTS

Mostly cooking devices use fire as source for cooking. Hence, fire liberates heat which can be utilized further to convert into useful energy. The TEG converts heat energy directly to electrical energy. The TEGs were acquired from Hi-Z Technology. Two types of TEGs were acquired namely HZ-14 and HZ-9 of 14 W and 9 W resp. The performances of the two TEGs were verified by measuring the hot and the cold side of the TEG with thermocouples. The open circuit voltage is measured across the terminal of the TEG and the current is measured with a current sensing resistance if 0.005Ω in series with the TEG. The hot side of the TEG is placed on a 1 cm thick aluminium plate. The cold side was mounted by a 16cm x 11cm x 7cm parallel plate aluminium sink. A 5V 0.32 A fan was mounted on top of the sink. The air of the fan is also used to feed inside the combustion chamber to increase the air to fuel ratio.The hot side was maintained with a constant continuous 230˚C on the hot plate. Fig 4 shows the integration of TEG with the prototype stove.

Fig 4. TEG integrated cookstove prototype

The performance of HZ-14 and HZ-9 is illustrated by graph 1(a) and graph 1 (b).



Graph 1: Relation of open circuit voltage, load voltage, current and power with respect to temperature difference on both the sides of (a) HZ-14 (b) HZ-9.

The graph 1(a) of HZ-14 shows that the power output of the module is as high as 14 W. This is due to high current output of nearly 8 A but the open circuit voltage is only 3.5 V and load voltage (at matched load) is 1.5 V. Due to low voltage output DC-DC boost converter which can work from millivolts to volts is required because it cannot be expected that the TEG always produces constant ΔT. The ΔT is deviates due to joules heating which tent to saturate the cold side temperature with the hot side temperature. Therefore it results to mostly low power output for most of the time. The cost of the HZ-14 is also high of about $85/module and $40/10000 module. Due to these limitations of HZ-14, a HZ-9 module is chosen for the application. The graph 1(b) shows that the power output of HZ-9 is lower than HZ-14 but the open circuit voltage of HZ-9 is 6.9 V and load voltage (at matched load) is nearly 3 V, hence it is reliable and easy to boost 3 V load voltage. The cost of the HZ-9 is $45/module and $20/10000 module which is cheaper than HZ-14.

4. CONCLUSION

The TEG HZ-9 is chosen for the required application. The heat from the cookstove is utilized by the TEG to directly convert heat into electricity. The power generated from the TEG is about 3 W. The power output is required to run a small DC brushless fan which cools the cold side of TEG and directs the air to the combustion chamber to improve combustion. The generated voltage is boosted upto 5.2 V by a DC-DC boost converter and charges a mobile phone and glow LED lights. The technology is viable for rural household where homes are not connected to grid.

REFERENCES

[1] WHO. Fact sheet No. 292: indoor air pollution and health; 2011.

[2] WHO. Global health risks: mortality and burden of disease attributable to selected major risks; 2009.

[3] Killander A, Bass JC. A stove-top generator for cold areas. In: Proceedings of the15th international conference on thermoelectrics; 1996 Mar 26–29; New York, USA. New York: IEEE; 1996.

[4] Mastbergen D. Development and optimization of a stove-powered thermoelectric generator. Colorado State University; ETHOS 2008.

[5] Champier D, Bedecarrats JP, Kousksou T, Rivaletto M, Strub F, Pignolet P. Study of a TE (thermoelectric) generator incorporated in a multifunction wood stove. Energy 2011; 36:1518–26.

[6] Cedar, Jonathan M. (Scarsdale, NY, US), Drummond, Alexander H. (Austin, TX, US),"Portable combustion device utilizing thermoelectrical generation",8297271.

[7] S.M. O'Shaughnessy, M.J. Deasy, C.E. Kinsella , J.V. Doyle , A.J. Robinson. Small scale electricity generation from a portable biomass cookstove: Prototype design and preliminary results, Applied Energy 2012.

[8] David Michael Rowe , Thermoelectric waste heat recovery as a renewable energy source, International Journal of Innovations in Energy Systems and Power, Vol. 1, no. 1, 2006

[9] H.J. Goldsmid. Applications of Thermoelectricity, Methuen Monograph, London, 1960.

[10] C.M. Bhandari, and D.M. Rowe, Thermal Conduction in Semiconductors, Wiley Eastern Ltd, 1988.

[11] Min G, Rowe DM. Peltier devices as generators, CRC Handbook of thermoelectrics Chap. 38. London: CRC Press, 1995.

[12] Rowe DM. Evaluation of thermoelectric modules for power generation. J Power Sources 1998; 73: 193–8.

[13] Rowe DM, Min G. Design theory of thermoelectric modules for electric power generation. IEEE Proc-Sci Meas Technol 1996; 143(6):351–6.

[14] R.Y. Nuwayhid, D.M. Rowe, G. Min. Low cost stove-top thermoelectric generator for regions with unreliable electricity supply. Renewable Energy 28 (2003) 205–222.

[15] Risha Mal, Rajendra Prasad, V.K. Vijay. Renewable Energy from Biomass Cookstoves for Off Grid Rural Areas. International Proceedings of chemical, biological and environmental engineering, vol 64.