# THERMOELECTRIC POWER GENERATOR INTEGRATED COOKSTOVE: A SUSTAINABLE APPROACH OF WASTE HEAT TO ENERGY CONVERSION

**Risha Mal[1], Rajendra Prasad[2], Virendra Kumar Vijay[3], Amit RanjanVerma[4], Ratnesh Tiwari[5]**

*[2]Centre for Rural Development and Technology, Indian Institute of Technology, Delhi*

## Abstract

*A prototype is developed for thermoelectric power generator module integrated with a double chambered forced draft cookstove. A module of an appropriate rating is chosen for the testing and then power generation is observed. The voltage generated is further stepped-up using a DC-DC step-up converter to run a DC brushless fan of 5V, 0.3A. The fan serves two tasks, first is to cool the one side of thermoelectric power generator and second is to supply the air to the combustion chamber of cookstove. The air is directed to the combustion chamber through a duct which increases the air-to-fuel ratio which helps for a cleaner combustion. A net output of 4W is generated from the thermoelectric power generator.*

***Keywords:*** *Electrical internal resistance, Operating temperature, Thermoelectric power generation*

-------------------------------------------------------------------***-------------------------------------------------------------------

## 1. INTRODUCTION

Biomass is the primary fuel for cooking in rural areas of India. People still rely on natural resources like wood, cowdung, agricultural waste as fuel and built the cookstove with bricks and clay, which gives an investment free cooking. About 25% of global black carbon is accounted by emissions from cookstoves. The Global Burden of Disease (GBD) Study 2010 ranks household air pollution as the fourth worst overall health risk factor in the world and as the second worst health risk factor in the world for women and girls and also doubled the mortality estimates for exposure to smoke from cookstoves, referred to as "household air pollution," from two million to four million deaths annually in the developing world [1].

The traditional cookstove has a very low thermal efficiency and emits lot of particulate matter and carbon monoxide. In order to improve the thermal efficiency and reduce emissions a small DC brushless fan is connected to provide sufficient air-to-fuel ratio to attain complete combustion. Generally these kinds of cookstoves are double chambered. The inner chamber has number of holes in the lower bottom and upper half of the combustion chamber to feed sufficient air for cleaner combustion.

Many Indian villages have no access to electricity and therefore the concept of fan driven improved cookstove fails in those areas. The waste heat of the cookstove can be utilized for the generation of electricity using a commercial thermoelectric generator (TEG). The heat from the fuel burnt is used for heating the hot side of the TEG and the cold side is attached with a sink to increase the surface area and dissipate the heat keeping the cold side cooler.

Due to the semiconductor material science technology the thermoelectric generation practical applications got high emphasis of conversion of waste heat into electricity. The principle of 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 module is of valuable due to its power generating feature and making the cook stove economically viable. The features like reliability and ruggedness of semiconductor material that came from solid state function has made this technology more viable and useful. The TEG has no moving parts; hence the operation is very silent. There is almost no effect of weather conditions that affect the operation of the TEG unlike solar panels.

## 2. PREVIOUS TEG COOK STOVE RESEARCHES

The concept of TEG integrated stove research was first done by J .C Bass and Killander in 1996. The stove performances according to the power output and the type of cooling are summarized in the table 1. The concept of this stove was taken from Biolite. The main motive is to make the stove very affordable to rural people and those who are devoid of electricity. There are many ways of cooling the TEG such as: heat sink attachment and ambient cooling, heat sink and fan mounted on top (forced convection), water cooling, forced water cooling (changing of water once heated), water cooling and fan mounted above.

**Table 1:** prior stove researches

| *Authors* | *Heat sink (Cold sink)* | *Type of module* | *Power/ module* |
|---|---|---|---|
| Nuwayhid 2003 | Natural air cooling | Peltier | 1W |
| Nuwayhid 2005 | Natural air cooling | See beck | 4.2W |
| Nuwayhid 2007 | Heat pipes cooling | See beck | 3.4W |

| | | | |
|---|---|---|---|
| Lertsatitthanakorn 2007 | Natural air cooling | See beck | 2.4W |
| Mastbergen 2007 | Forced air cooling(1 W) | See beck | +4 W |
| Biolite 2009 | Forced air cooling(1 W) | See beck | +2W |
| Champier "TEGBioS" 2009 | Water cooling | See beck | 5W |
| Champier "TEGBioSII" 2009 | Water cooling | See beck | 9.5W 7.5W regulated |
| Rinalde 2010 | Forced air cooling | See beck | 10W |

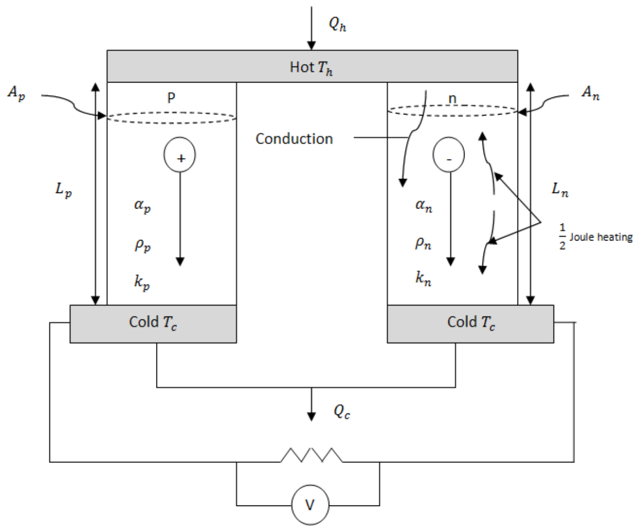


**Fig. 1:** Single thermocouple [11]

## 2.1 Thermoelectric Principles

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 $V = \alpha\Delta T$, where, $\Delta T = T_h - T_c$ and $\alpha$ is the Seebeck coefficient or thermopower expressed in $\mu V$ and the sign of $\alpha$ 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 or thermo elements. The TEG module has many semiconductors thermoelements 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. A single thermocouple comprises of two thermoelement, p-type and n-type. The themoelements of the n and p-semiconductors are connected thermally in parallel and electrically in series.

After thirteen years of Seebeckeffect discovery J .Peltier observed the second thermoelectric effect known as Peltier effect. According to Peltier effect the passage of an electric current through a thermocouple produces a small heating or cooling effect depending on its direction.

The interdependency between Seebeck effect and Peltier effect was determined by W .Thomson later known as Thomson effectconsists of reversible heating or cooling when there is both a flow of electric current and a temperature gradient.

## 2.2 Mathematical Modeling of TEG

The application of TEG is used in generation of electrical power. Now-a-days in the dearth of power TEG is a sustainable approach to generate electricity. To obtain the performance theoretically a single thermoelement is considered. The efficiency of the thermoelement depends on the value of load resistance and the properties of the semiconductor material. The fig 1 shows the arrangement of thermoelement in the TEG.

A thermocouple consists of p and n type thermoelement. Most of the commercial modules available in the market are made of Bismuth Telluride (Bi2Te3)semiconductor material. Heat flowing from one face of the module involves three effects: heat associated with Seebeck effect, the half of Joule heating and thermal conduction of the semiconductor materials. The heterogeneous material composition inside the thermoelements and the dissimilar geometry introduces dissimilarity in both p and n type materials. Hence the analysis of dissimilar elements is considered during calculation. The electric circuit defining the See beck coefficient of the p and n type is given as in equation 1, where and is the Seebeck coefficients of p type and n type material respectively.

$$\alpha = \alpha_p - \alpha_n$$

The electrical internal resistance R and the thermal conductance Kis defined as:

$$R = \frac{\rho_p L_p}{A_p} + \frac{\rho_n}{A} \text{ and } K = \frac{\lambda_p A_p}{L_p} + \frac{\lambda_n}{L}$$

Where $\rho_p, L_p, A_p,$ is the resistivity, length, cross section area and conductivity of p type material respectively. The resistivity, length, cross section area and conductivity of n type material is given by $\rho_n, L_n, A_n,$ respectively. These equations are used to model the behavior of TEGs are based on the Seebeck, Fourier and Joule effects.

Heat is applied to one face of the TEG and simultaneously removed from the other side to keep the cold face relatively cooler. The rate of heat supply is ( and heat removal ( can be estimated at the hot and cold junctions by the given equations:

$$Q_H = K(\Delta T) + (\alpha_p - \alpha_n) I T_h - \frac{I^2 R}{2}$$

$$Q_C = K(\Delta T) + (\alpha_p - \alpha_n)IT_c - \frac{I^2R}{2}$$

Where $\Delta T$ is the difference of temperature between the hot and cold surface, $\Delta T = T_h -$ and I is the current flowing in the electrical circuit. The voltage generated is given by the product of See beck coefficient and temperature difference;

$$V = (\alpha_p - \alpha_n)(\Delta T)$$

The current I produced by the thermocouple is given as;

$$I = \frac{(\alpha_p - \alpha_n)(\Delta T)}{R_L + R}$$

Where, $R_L$ is the load resistanand R is the internal resistance of the thermocouple.

The power is derived from the difference in rate of heat supply and rate of heat dissipated. Hence, the given equation for power output is given as:

$$P = (Q_H - Q_C)$$

The power output is also given as $P =$, therefore putting the value of current I and voltage V

$$P = \left(\frac{(\alpha_p - \alpha_n)(\Delta T)}{R_L + R}\right)^2 R_L$$

A thermoelectric module generates maximum power when the module resistance matches the load resistance, i.e. when $R_L$ = R. It follows that maximum power,

$$P_{max} = \frac{(\alpha_p - \alpha_n)(\Delta T)^2}{4R} = \frac{(\alpha_p - \alpha_n)(\Delta T)}{8\rho L}.$$

The power produced by each thermocouple is approximately proportional to its cross-sectional area, and inversely proportional to its length. Hence, the power produced by the TEG is entirely dependent on the number of couples N and the ratio of the TEG. The method utilized is known as Seebeck co-efficient model, which calculates the Seebeck co-efficient under actual load conditions. This is considered since TEG operates differently in open circuit and on load conditions. The maximum power output depends on matched load with the internal resistance of the module.

### 2.3 Experimental Setup

Peltier module was selected to work as generator. The heat input at the hot side is 200˚C and cold side of 30˚C. It was observed that the open circuit voltage at required $\Delta T$ is 2.5 V but the current output is 220mA. Since the power output of the peltier module is very low, a TE power generator is considered for the required operation. A 14 W module HZ-14 was taken for testing in an external environment. The external environment was made with a heater of temperature 600˚C which complements the temperature inside the cookstove. The module works on continuous 250˚C on hot side. The hot side temperature may extend upto 360˚C and intermittent 400˚C. The cold side temperature is to be maintained to 50˚C to get maximum power output from the module. The hot side is attached with 7 x 7 x 2 $cm^3$ thick aluminium block. The cold side is attached with a sink that resembles with the sink used by Nuwayhid et al [4] as shown in fig 2.

**Fig 2:** Heat sink for the cold side of TEG

The cold side is properly insulated with glass wool so that the radiation heat does not affect the temperature on the cold side. The temperatures on the hot side and the cold side were recorded continuously with K-type thermocouples. The aim of the experiment was to check the module performance by providing desired temperature difference. The first experiment was performed in ambient condition. The second experiment was done by forced air cooling using a fan mounted in top of the sink. It is observed that the power output of the HZ-14 module is very high as, but the individual voltage and current output was not sufficient as per our requirement. The voltage output of the HZ-14 is quite low and the current is very high.

Hence, the HZ-9, a 9W TEG module was selected for prototype development. This module has aVoc(max) of 6.5V. The module was considered appropriate since it is relatively easier to boost the voltage where we get output voltage soon. The arrangement of TEG for running a fan of 5V is given in fig 3.

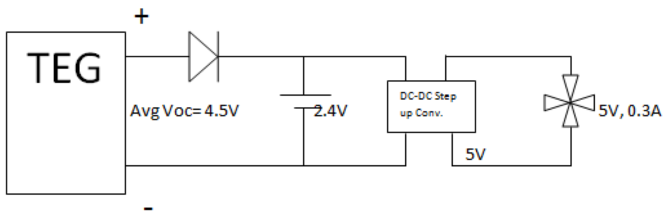


**Fig 3:** Circuit Diagram TEG arrangement

## 3. RESULTS AND DISCUSSIONS

The module HZ-9 is selected for prototype development. The module was tested with an external environment and a maximum power of 4W was achieved. The inner combustion chamber that was chosen for implementation was designed by Tata Energy Research Institute, Delhi, India. Further modifications were incorporated for the placement of the

TEG module. The performance of TEG with respect to time versus open circuit voltage when 1Ω resistance is connected as load is shown in fig 4.

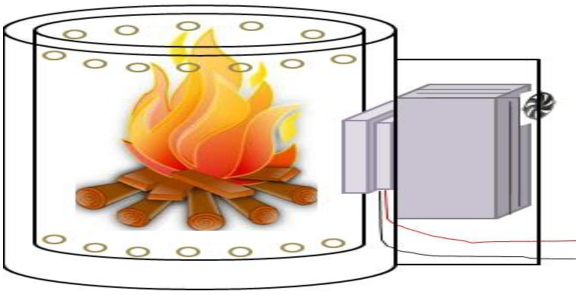

**Fig 3:** Schematic diagram of prototype design

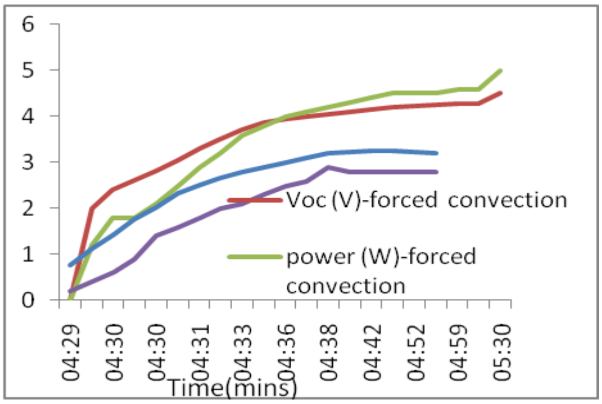


**Fig 4:** TEG performance with Time versus open circuit voltage and power output when connected with 1Ω resistance in natural convection with heat sink alone and forced convection with fan mounted on top of heat sink.

It is observed that the performance of TEG increases with forced convection. The relation of temperature difference with respect to open circuit voltage in forced convection is shown in fig 5.

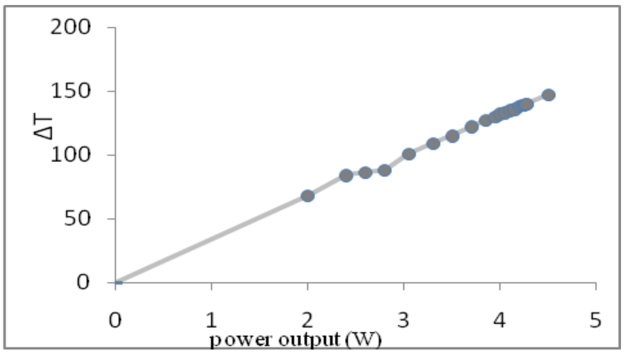


**Fig 5:** Relation of temperature difference (ΔT) with respect to power output (W) with load of 1Ω resistance.

After the confirmation of the performance of the TEG with the particular heat sink it was observed that the power output is sufficient to run a 5V, 0.3A brushless DC fan. The TEG was mounted on the inner combustion chamber by cutting an opening on the opposite of the feeding area. The outer jacket of the cookstove was made by tin sheet. The entire cookstove is then covered with mud/clay. At best of our knowledge, this is a first prototype that is doubled chambered forced draft mud stove that is integrated with TEG. The fig 4 shows the prototype that is developed for testing.

**Fig 6:** Front and rear view of the TEG integrated improved mud stove.

The performance of the TEG when integrated with the stove remains the same as expected. A DC-DC step up converter is connected on the output of the TEG. The DC-DC step up converter step up 1V input to constant 5V. When the voltage reaches 2.3V, the fan rotates at full speed consuming 0.3A current. The output of the TEG is 4-4.5W. Hence around 3W is wasted in the process. It is wiser to store the excess energy and use it in other purposes.

## 4. CONCLUSIONS

The module performance is higher than what is produced in the present practical application. This is due to low ΔT attainment. Different heat sinks are experimented to extract highest performance from the module. The present stove performance is enough to run a clean forced draft cookstove in off-grid rural area. The cost of the cookstove is to be kept within 3000 INR. Since it is a onetime investment and in view of cleaner combustion it is a worthy sustainable approach.

## REFERENCES

[1] A. WHO:Household Air Pollution Findings, Global Burden of disease; 2010.

[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] 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

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

[6] 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.
[7] Champier D, Bedecarrats JP, Rivaletto M, Strub F. Thermoelectric power generation from biomass cook stoves. *Energy* 2010;35:935–42.
[8] Cedar, Jonathan M. (Scarsdale, NY, US), Drummond, Alexander H. (Austin, TX, US),"Portable combustion device utilizing thermoelectrical generation",8297271,
[9] 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
[10] 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
[11] H.J. Goldsmid. Applications of Thermoelectricity, Methuen Monograph, London, 1960.
[12] C.M. Bhandari, and D.M. Rowe, Thermal Conduction in Semiconductors, Wiley Eastern Ltd, 1988.
[13] Min G, Rowe DM. Peltier devices as generators, CRC Handbook of thermoelectrics Chap. 38. London: CRC Press, 1995.
[14] Rowe DM. Evaluation of thermoelectric modules for power generation. J Power Sources 1998;73:193–8.
[15] Rowe DM, Min G. Design theory of thermoelectric modules for electric power generation. IEEE Proc-Sci 1996;143(6).