EXPERIMENTAL EVALUATION OF BIOMASS STOVE THERMOELECTRIC GENERATOR WITH AND WITHOUT FIN

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ABSTRACT

This paper presents the combined heat and power analysis of biomass stove thermoelectric generator with and without metal fins of the absorber. The purchased biomass stove thermoelectric generator modified by adding the metal fin on metal road to enhance the heat transfer rate. The simple experimental test conducted with and without metal fins and found that with metal fins the power output is improved by 3%. The economic analysis carried out and it found the paypack period found as 20months comparing with diesel generator. It is concluded that the developed system will be further analyzed by keeping the metal road in the combustion chamber in square and rectangular position along with cost economic analysis.Keywords—component; Thermoelectric Generator, Figure of Merit, Biomass Stove, Overall Efficiency

INTRODUCTION

Energy poverty report during 2010, The Economic Co-Operation and Development (OECD) organization projected the investment of $36 billion per annum was essential to guarantee that each citizen in the world benefits from the access to electricity and fresh cooking facilities by 2030. Also, the report declared that a new dedicated policy was compulsory if the environments for the life of billions of people are to develop to a higher level. However, to create key decision on the subject of the welfare of their society and help refine policies over time, policy-makers should rely on quantitative information and analysis. Moreover, the number of people depending upon the conventional use of biomass is estimated to attain 2.8 billion by 2030. The trouble is particularly evident in Africa where the electrification status is only 31% and 80% of people burn biomass as their major source of household power.

In India, energy consumption per capita is about 631kWh and standard per capita (watt per person) is 50.5 W which is very small as compared to developed countries. In rural India 400 million (57% of the population) is lacking access to electrical energy. The majority of the rural houses are lack of electricity due to technical and economic feasibility. The minority of Indian villages has acquired domestic connections for electric lightning; remaining houses depends on kerosene lamps and candles.

The efficient utilization of heat energy in the cook stove can supply 5-10 W to cover up vital requirements of the publics such as lightning and mobile charging to the low income populations, living generally in rural part of the country. The thermoelectric generator (TEG) modules incorporated with cook stoves are a necessary and motivating opportunity to provide electricity.

Hence, it is a need of hour to develop an integrated system that generates both electricity and heat in biomass cook stove will solve the rural problems. Thermoelectric generators have the feature of solid state energy converter for electricity generations from excess/waste heat in the stove of biomass. The use of thermoelectric generators for waste heat to electricity conversion is not a fresh method, but maybe this is only way now to becoming more evident in every day applications. Codecasa (2013) developed a 5W, 12V TEG system with the target of powering standalone gas heater for commercial outdoor exercise. The TEGs have been predominantly limited to low power demand systems. Doloszeski and Schmidt (2010) investigated the application of a large thermoelectric module which combined with a fluidized bed combustor to attain up to 450W of electrical power. Many researchers have investigated the potential for TEGs in low temperature waste heat harvesting has been based on laboratory scale. The ideas of integrating thermoelectric generators with cook stoves have been investigated; several studies have been focused on optimizing the TEG output under fixed parameters. Even though this method does offer appreciated information on the performance of the generator, the test conditions are to be strictly controlled, then the heat source in many cases is derived from an electrical power supply rather than the more inconsistent conditions encountered during combustion.

Rural part of others developed nations, where electricity supply is not reliable, and the feasibility of adding a commercial TEG to the stove is investigated. Indeed, it is possible to create a TEG system including the conversion of a part of the wasted heat. With the use of TEG generators, the different functions of the domestic stove are increased (cooking, water heating, space heating and electricity supply). Low conversion efficiency of TEG not constraint if the sources of heat available at free of cost, the electric power is sufficient to supply a small fan to improve the combustion in the stove, charge a battery and power LEDs lamps. The fan creates forced circulation the air through the stove, prominent to higher temperatures and an improved air/fuel ratio. This results the clean combustion and a higher efficient of fuel. The TEG power generations have the advantages of maintenance free, noiseless in operation and involving no complex parts.

The aim is to product design and analysis of biomass stove integrated with thermoelectric generator with and without fins for generation of heat and electricity. The projected power generation from the TEG is 5-10 W for running an integrated fan for complete combustion inside the chamber and also for basic requirements like lighting, radio and charging cell phone as well as other electrical appliances. The cook stove is equipped with thermoelectric power generator attached in chimney or in the body of cook stove, which can be fed with hot flue gases from cook stoves and ambient and can create the temperature difference. There is limited published research on the topic of integrating TEGs with cooking stoves, particularly those intended for developing countries. Typically, studies involve the investigation of the output power generated by stoves with integrated TEGs in a laboratory setting, such as studies (Eakburanawat et al., 2003; Lertsatitthanakorn, 2007; Nuwayhid and Hamade, 2005; Nuwayhid et al., 2003; Rinalde et al., 2010).

THERMOELECTRIC POWER GENERATION

The thermoelectric potential of the material will determine in the large part by measurement of the material's figure of merit, *ZT*:

$$\mathrm{ZT} = \frac{\alpha^2 \sigma \mathrm{T}}{\mathrm{K}} = \frac{\alpha^2 \mathrm{T}}{\rho \mathrm{K}} \quad (1)$$

where, α is the Seebeck coefficient, σ is the electrical conductivity, ρ is the electrical resistivity, and K is the total thermal conductivity.

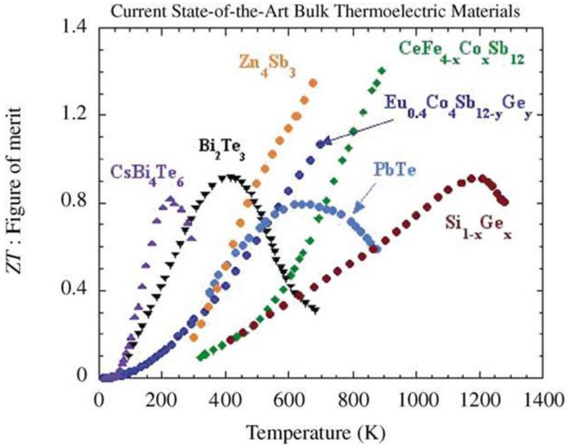

Figure 1: The figure of merit (ZT) for several bulk thermoelectric materials with temperature[3]

$$\eta = \frac{W}{Q_H} \quad (2)$$

$$\eta = \frac{T_H - T_C}{T_H}\left[\frac{(1+ZT_M)^{1/2} - 1}{(1+ZT_M)^{1/2} + \left(T_C/T_H\right)}\right] \quad (3)$$

(4)

Where, T_H is the hot-side temperature, T_C is the cold-side temperature, and T_M is the average temperature. Thus, one can see that η is proportional to $(1+ZT_m)^{1/2}$ and that the efficiency would approach the carnot efficiency if *ZT* were to approach infinity.

The power factor, $\alpha^2\sigma T$ (or $\alpha^2 T/\rho$), is typically optimized in narrow-gap semiconducting materials as a function of carrier concentration, through doping, to give the largest ZT. High-mobility carriers are most desirable, in order to have the highest electrical conductivity for a given carrier concentration. The ZT for a single material is somewhat meaningless, since an array of thermoelectric couples is utilized in a device or module.

The efficiency (η) of the thermoelectric couple is given by the power input to the load (W) over the net heat flow rate (Q_H), where Q_H is positive for heat flow from the source to the sink:

FUTURE THERMOELECTRIC MATERIALS

The future of technology for the conversion of thermoelectric energy is tied largely to enhanced materials performance along with further thermal management design. The finest thermoelectric material should perform as a so-called phonon-glass-electron-crystal; that is, it should minimally scatter electrons, as in a crystalline materials, where as it should highly scatter phonons, as in a crystalline material, whereas it should highly scatter phonons, as in amphorous materials. Material researchers are now investigating several systems of materials including typical narrow band gap semiconductors (half-Hauler alloys), oxides and cage-structure materials (skutterudities and clathrates). More exotic structures that exhibit reduced dimensionality and nano-structures have been the focus of much recent research, including super lattices, quantum dots and nano dot bulk materials. Also, recent progress in nano-composites, mixtures of nano materials in bulk matrix, has generated much interest and hope for these type of materials. The emerging field of these thermoelectric nano-composites could allow for higher *ZT* values by reducing thermal conductivity while maintaining favorable electronic properties. With ne higher efficiency materials, the field of harvesting waste energy through thermoelectric devices will become more prevalent.

The most stable, long-term and readily available worldwide energy source is that f solar energy. The issue has always been low-cost transformation and storage. Other alternative technologies such as fuel cells, wind energy and thermoelectric will provide some assistance in fulfilling our future need for the energy. Many hybrid systems will be needed and thermoelectric is able to work in tandem with other technologies, especially solar as it will use heat source provided by solar radiation. Over the past decade, thermoelectric materials have been developed by *ZT* values that are factor of 2 larger than those of previous materials. Another 50|% increase in *ZT* with appropriate materials characteristics and costs will position thermoelectric to be significant contributor to our needs for energy, especially in waste heat or solar energy conversion. The likelihoods of achieving these goals appear to be within reach in the next several years. Furthermore, some contribution from many of this alternative energy technology such as thermoelectric will be needed in order to fulfill the world's future energy needs.

It is the need of the generator module but the exchanger can be manufactured and assembled in a local workshop. The produced electricity has run the fan in the cook stove to increase the secondary air circulation and improves the combustion efficiency. This reduction agrees on fuels consumption and the emission level. Additional electricity storage is available to power LEDs.

The objective of this paper is to product analysis of biomass cook stove by increasing the area of contact of the copper plate which will absorb the heat from the combustion chamber. As the heat absorption by the copper plate is increased, and then the heat transferred to the thermoelectric generator also is increased. If the temperature difference between the hot side and cold side of the thermoelectric power generator is more than 200°C then, the electrical energy generated will be more. The temperature difference between the hot side and the cold side of the thermoelectric power generator should be maintained 200°C and above so that the output also be very high.

EXPERIMENTAL STUDIES

In this experiment, the biomass thermoelectric cook stove (***Make: BioLite, USA***) used. An air cooled heat sink based thermoelectric power generator is attached to the combustion chamber through metal bar. *i.e*, the hot side of the thermoelectric power generator is connected to the copper strip which is having a diameter of 1cm and around 5 cm long. This copper strip will be inserted into the combustion chamber before the use. The cold side of the TEG is attached with the aluminum fins which help in the cooling process. This TEG is connected to a circuit which helps to store the electricity to the battery which is produced during the combustion process. Also there is small fan which is attached to the system and this fan will be working the electricity stored in the battery during the process. There is a USB port is available for the output i.e., for charging mobile phones, lights, etc. Aluminum heat sink with fins was mounted on the cold side of the thermoelectric modules. Thermal grease is used to enhance heat transfer between the surfaces. Two different cooling systems are tested to maintain a constant temperature on the cold side. The temperatures, tension and current were recorded by using a Data Logger. The measurement system permits us to obtain a precision of 0.01% for the tension, 0.1% for the current and of 0.5 °C for the temperatures.

TABLE I SPECIFICATION OF BIOMASSSTOVE THERMOELECTRIC GENERATOR

Parameters	Value
Weight	935 grams
USB power output	2W @ 5V (continuous) & 4W @ 5V (peak)
Pot weight limit	5kg of liquid
Fuel :	Renewable biomass (twigs, wood pellets, etc)
Estimated fire output	3.4 kW (low) &5.5 KW (high)

But, because of the difficulty to measure a surface temperature accurately, the temperature errors are evaluated to 1°C. The honey comb like structure will help to pass sufficient amount of heat to the combustion chamber. It helps to burn the biomass completely without any wastage of biomass fuel and less carbon dioxide will produced.

For carrying out the experiment the area of contact should be increased by attaching another metal strip to the copper strip so that the heat conduction would be higher as more area is exposed to the heat.

Figure2: Photographic View Biomass Stove Thermoelectric Generator

The selection of the metal strip should be done by considering the thermal conductivity of the metal.

A rheostat was connected to the TE modules as a load, and the resistance RL set at different values in the range 1–10 Ω. The measured power P_o that can be produced by one TE module as a function of the electric load R_L .The temperature difference (ΔT) between the hot side and cold side of the TE module is about 100°C. The model base power assuming for the TE generator have an internal resistance (R_{int}) of 1.75 Ω and an open-circuit voltage (V_{oc}) of 2.65 V for comparison. The comparison between the experimental results to that of the model permits to validate the experimental procedure.

The variation of the voltage (Vo) and output power (Po) characteristics for an electric load of 2 Ω of the TE module as a function of the temperature difference (ΔT) between the hot side and cold side of the TE module. The electrical characteristics of the TE modules were tested in steady state and dynamic conditions by using steps of the electric heat power from 0 to 150W. For the determination of the efficiency of the biomass thermoelectric stove and the modified biomass thermo-electric stove. The stove should be operated by using the same amount and same type of fuel and both will be carried at the same period of time.

The measurement should be taken and the values should measure are temperature of the hot side of the thermoelectric generators, the charge of the storage battery before and after the each experiment and the current produced during the experiment. The mass of the fuel that is burned on each experiment should be measured and they should be equal. The figure 2 shows the photographic view of biomass stove thermoelectric generator during startup and after startup. After startup, LED green lights glow indicates that electricity is generated and stored in the small battery attached in the system.

In the cooking stove, electricity is necessary to power the fan as air blowing through the stove increases the air/fuel ratio and so achieves a complete combustion. At the beginning of the burning, the temperatures are very low and electricity is not available from the TE generator, so it is necessary to charge a battery. The improved stove eliminates the light produced by the traditional open fire. So it is important to produce some light in the cooking room in a different way. So the electrical load of our TE modules will be a battery, a fan and other devices that are connected through the USB output. The figure 3 shows the electrical portion of the setup and its consists of thermoelectric generator, electrical fan and battery with heat sink.

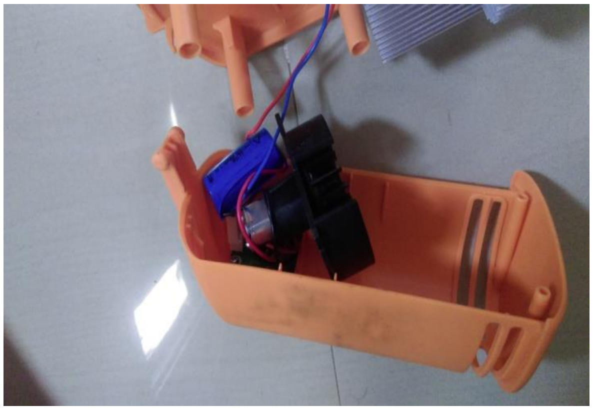

Figure 3: Electrical part

The bismuth telluride module works at a temperature of 260 °C continuously and occasionally up to 380 °C heat source without degrading. The cold side of the thermoelectric generator cannot go beyond the temperature of 165°C and its construction uses two methods of bonding.

The hot side often uses aluminum is having a melting point temperature of 660 °C to bond the elements while the cold side elements use 3% silver solder rated at temperature of 220°C. It is necessary to make sure that the cold side sink is active based on water cooled medium. There are a few points to take into account to design and locate the thermoelectric generator:

The very low heat flux calculated above,

The average temperature fluctuation between a maximum temperature of 400 °C and a minimum temperature of 200 °C depending on the part of the chamber considered,

The very high temperature reached by the combustible gas at the input.

To increase drastically the heat flux, it is needed to design a combustion gas based heat exchanger. The first idea is to put the module middle up along the tank where the gas temperature is below 300 °C and to collect the heat with a lengthy exchanger along the tank down to the gas involvement. This would allow a more reasonable heat flux and average the temperature but it would escalation pressure drop due to heat exchanger ensnaring. The second idea is to use the large cooking plate as the hot heat exchanger and to usage a secondary tank linked to the main tank as cold heat exchanger. Owing to the uneven feeding rate of biomass and to the use of heat for cooking, the combustible gas temperature not is quite steady and the output voltage will fluctuate a lot. We have to develop the electronic part to get reasonable electrical energy of the same frequency.

COST ANALYSIS

The cost analysis of the proposed biomass stove thermoelectric generator was estimated and related with the cost of energy supplied when compared with diesel generator to a 40 W load (an incandescent light bulb). Payback period was employed to determine the period of time required for the biomass stove thermoelectric generator to pay for itself by replacing purchased diesel generator. Payback period was defined as the time required for the biomass stove thermoelectric generator investment to equal the diesel generator investment.

TABLE II CONDITION FOR ECONOMIC EVALUATION

Item	**Biomass Stove Thermoelectric Generator**
Load (40W)	Light Bulb
Investment (INR)	INR 20000/-
Operating Cost	NIL

Interest Rate	10%
Life Cycle	15 Years
Diesel Generator (INR)	INR 10000/-

The payback period was confined to an analysis of diesel generator replacement cost. The payback analysis is conducted to compare between the ongoing diesel generator cost and biomass stove thermoelectric generator. Since the biomass stove thermoelectric generator system not designed as a permanent replacement for diesel generator power.

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The evaluation parameters for the economic analysis are summarized in Table II. During 2016, the interest rate of the State bank of India bank is approximately 10%. The economic evaluation of the biomass stove thermoelectric generator compared with the cost of energy supplied to a 40 W load at various operating time is shown in Fig. 4.

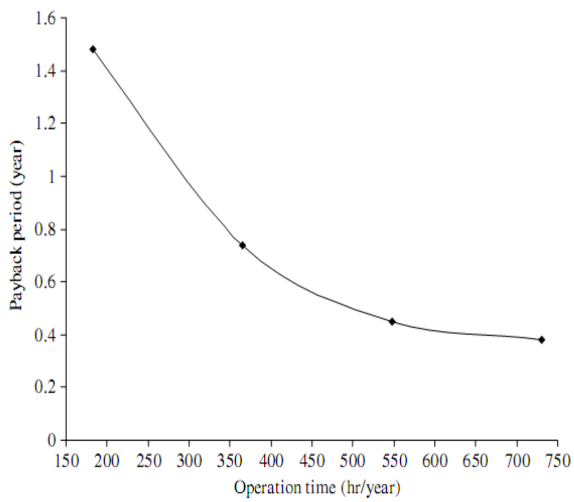

Figure 4 Paypack time with operating hours

It could be found that the payback period based on 360 h annual operating time of the biomass stove thermoelectric generator is 20 month. In addition, it can be noted that the higher the annual operating time, the higher the potential to use the biomass stove thermoelectric generator is obtained.

IV CONCLUSION

It is concluded from the study, commercial biomass stove thermoelectric generator was modified the heat receiver metal with extended fins. The performance evaluation made with and with without fins it is found that with fins gives 1 percent higher than the without fins. The economic analysis made when compared with diesel generator and found that 20 months years as payback period when compared to diesel generator. It is also concluded that, It is clean energy conversion system and energy efficient biomasses stove both to cooking needs and generate electricity for isolated rural parts. The electrical power output of the system depends on the heat transfer rate on the both sides of the thermoelectric module; a specific consideration should be paid to the design and development of the heat exchangers or using heat transfer fluid or materials. Future work will consist in testing the efficient thermoelectric modules into the improved biomass stove.

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