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Thermoelectric Waste Heat Recovery as a Renewable Energy Source

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***Abstract**:*

Waste Heat Recovery is actually a mechanism which involves the method of transferring or exchanging the amount of heat of a certain emitted stream with a certain component. Since most of the waste heat is being transferred or released to the environment, so using the amount of energy of that waste heat is practically an economical idea. In this describes the design of an energy efficient biomass cook stove for developing countries to accomplish the requirement for both, cook stoves itself and electricity generation. For a simple and low cost application of a rural cook stove, commercially available thermo electric modules are tested and the suitable module is determined for selection.

Keywords: *Heat sinks, thermoelectric generator (TEG), stove, thermocouple.*

1.Introduction

In our day to day life we come across to see various processes that involve the emission of heat, and we term this emitted heat as Waste heat. Waste Heat Recovery is actually a mechanism which involves the method of transferring or exchanging the amount of heat of a certain emitted stream with a certain component. Since most of the waste heat is being transferred or released to the environment, so using the amount of energy of that waste heat is practically an economical idea. Biomass is the primary fuel for cooking in rural areas of India. People still rely on natural resources like wood, cow dung, agricultural waste as fuel and built the cook stove with bricks and clay, which gives an investment free cooking. About 25% of global black carbon is accounted by emissions from cook stoves. 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 cook stoves, referred to as "household air pollution," from two million to four million deaths annually in the developing world.

It is also observed that most of the modern kitchens have gas stove as primary equipment and electric chimneys as its secondary equipment. If we go into the engineering aspect the heat energy released by the LPG through gas stove is used for cooking. As we all know that whole of the heat cannot be used therefore is wasted to the kitchen atmosphere and further to the environmental atmosphere by the help of the chimneys. In order to remove this excess heat we install chimneys. The idea behind the proposed design is to use this so called waste heat, to heat up water and use it for various residential purposes.

1.1 Problems associated with traditional cooking method

1.The traditional cook stove has a very low thermal efficiency .
2.The cook stove emits lot of particulate matter and carbon monoxide.
3.The air to fuel ratio of the traditional cook stove is very low.
4. The excess of smoke coming out of cook stove causes many health problems and diseases

.

1.2 How thermoelectric prototype can help to overcome the problems

1. This prototype consist of a good facility to provide holes around the circumference of the cylindrical body which increases the air passage though the chamber and hence increases the air to fuel ratio.
2. This system helps to recover the heat which has been generally wasted in the process of cooking. The heat here has been effectively used to generate electricity.
3. This system is made portable which can be taken to any places , which is not possible in the conventional cooking stove.

2.Thermoelectric cooler/ thermoelectric generator?

It is our intent to become a major player in the field of Thermoelectric POWER generation shown in (figure 1) using the seeback effect. Incredible interest is building in this novel field. Estimates are that thermoelectric power technology will become

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more competitive than solar or wind technologies even with these technologies having a head start as far as deployment and technological advances. The pay back on thermoelectric power/watt is more economical presently, than both wind and solar, even with the smaller efficiencies that presently are available with today's materials

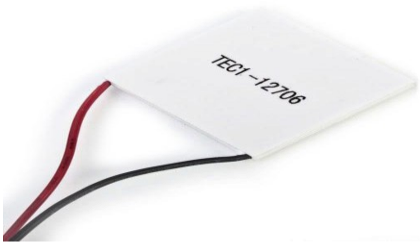

Figure.1 TEG Module

2.1 Development of thermoelectric system

Standard thermoelectric modules range in size from 4 x 4 x 3 mm3 to around 50 x 50 x50 mm3. Although, in principle, the dimensions can be reduced further, the fabrication of conventional thermoelectric modules for power generation or heating and cooling applications is a bulk technology, and is incompatible with microelectronic fabrication processes. The development of micro-thermoelectric devices that are compatible with standard microelectronic technology and manufacturing processes have the potential to enhance the performance of microelectronic systems, achieve significant reductions in size, improve the performance of thermoelectric devices, and open up new areas of research and commercial application.

Until recently, thermoelectric devices have been confined to niche applications because of their relatively low conversion efficiency an compared with other technologies. A typical thermoelectric module is composed of two ceramic substrates that serve as a foundation and electrical insulation for P-type and N-type Bismuth Telluride dice that are connected electrically in series and thermally in parallel between the ceramics as shown in (figure2).

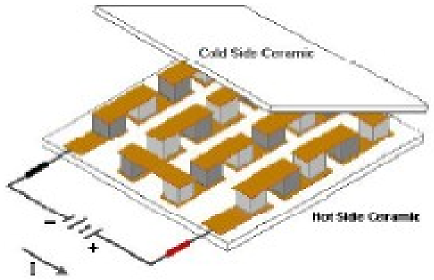

Figure.2 Internal thermoelectric module

2.2 DC-DC converters for TEGs :

When the temperature difference between the surfaces of TEG is changed, the output voltage of the TEG varies accordingly. It is required that standard voltage give to the loads or the electronic circuits connected to the ends of TEG.

Figure.3 DC-DC Step up converter

In order to provide this standard voltage, TEGs need to the DC-DC converters. TEGs are connected into the serial and parallel to achieve sufficient power . In a DC-DC converter, a power management circuit extracts power as many as possible from the TEG system connected into the serial and parallel and it generates the voltage needed by the electronic circuit. The open-circuit output voltage VOC of the TEG varies depending on the temperature difference ΔT between the surfaces of TEG. The voltage Vi, which is at the entrance of DC-DC converter, affects the internal impedance R in of TEG. In order to transfer a maximum power to the output, the impedance matching is needed. In this case, the input voltage Vi of the DC-DC converter is only half of VOC. Vi is determined by the output voltage VO and the conversion factor. Since the output of DC-DC converter is connected to a battery. VO is constant within a short time interval. Therefore, the conversion factor of a DC-DC converter can be adapted to reach matching for the TEG.

2.2.1Thermal Fin

It is used here for increase the thermal gradient value. When we increase the Thermal gradient value it increase the seebeck voltage generated by TEG. This FIN also transfers the heat from Thermoelectric Module. It is made by Aluminum metal. When we include Thermal fin it increase the efficiency of the TEG.

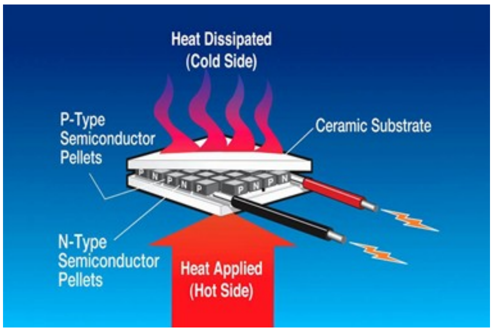

Figure.4 Thermal fin of TEG

Electric energy conversion have no moving parts. The thermal to electric energy conversion can be performed using components that require no maintenance, have inherently high reliability, and can be used to construct generators with long service free lifetimes. This makes thermoelectric generators well suited.

2.2.2Efficiency:

Their typical efficiencies are around 5–8%. Older devices used bimetallic junctions and were bulky. More recent devices use highly doped semiconductors made from bismuth telluride (Bi_2Te_3), lead telluride (PbTe),[3]calcium manganese oxide(CMO),[4] or combinations thereof,[5] depending on temperature. These are solid state devices and unlike dynamos have no moving parts, with the occasional exception of a fan or pump. For a discussion of the factors determining and limiting efficiency, and ongoing efforts to improve the efficiency

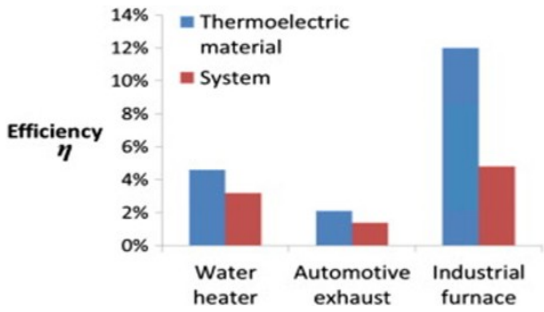

Fig.5 Efficiency of thermoelectric systems

3.0 Circuit diagram for single thermocouple:

The following figure6 shows the circuit diagram for a single thermocouple.

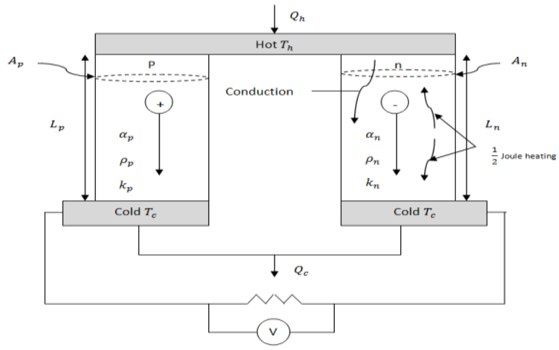

Figure.6 Single thermocouple.

3.1 Circuit diagram for the complete setup

The following (figure 7) shows the complete setup in the form of a circuit diagram :

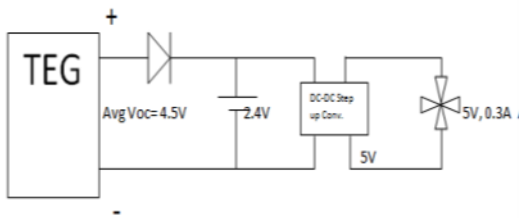

Figure.7 Circuit diagram of complete setup

The following observations can be made from the above circuit diagram:

1.The open circuit voltage produced by the TEG in the natural condition is around 2.4 volts.

2.For the further enhancement of the voltage the setup is connected with a DC-DC Step up converter or a voltage booster.

3.After connecting the set up with the DC-DC Step up converter or a voltage booster the output voltage is increased to 5 volts.

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4.Further the connections are given to the fan which operated by the current developed by by the TEG and enhanced by DC-DC converter.

5.Here the TEGs can be connected in series in order to produce more voltage. In the experiment we used two TEGs.

3.2Working of TEGs:

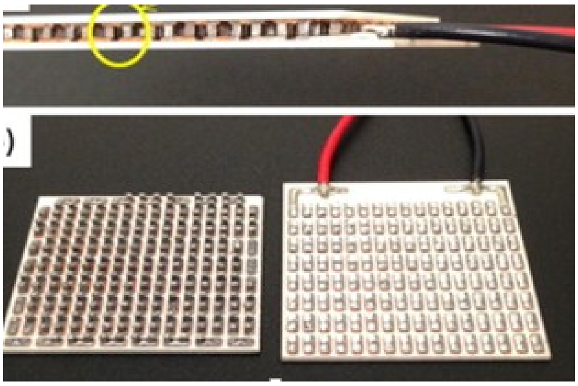

Figure 8. Interior shell of the TEG

Thermoelectric generators have been used to power space vehicles for several decades [1] and [2], so the research and development contributions and expertise from the space industry are invaluable in the development of terrestrial waste-heat recovery TEGs. Named radioisotope thermoelectric generators (RTGs), the heat source in spacecraft TEGs comes from the nuclear decay of radioactive isotopes. RTGs were selected to power space vehicles since they are highly reliable, robust, and compact. They are solid-state devices without the rotating machinery typical of other heat engines, so RTGs do not produce noise or vibration. These qualities made RTGs ideal for powering autonomous space vehicles with long life missions. RTGs for space power systems have unique characteristics which differentiate this application from the waste-heat recovery applications discussed here.

The heat source temperature is typically higher (~1000 °C) resulting in the use of thermoelectric materials such as silicon germanium which are suitable for high temperature power generation. The operating environments are outer space and other planetary surfaces.

Moreover, the cost–performance considerations and constraints for space vehicle development are significantly different than for waste-heat recovery applications since significant value is placed on the RTG primary power generation capability and unique suitability for the requirements of space applications.

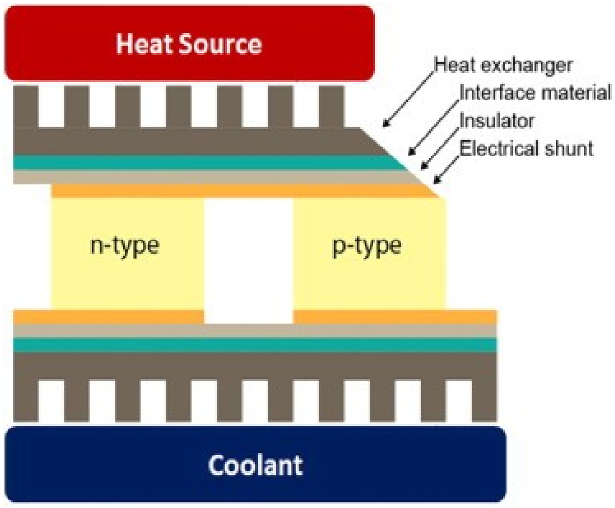

Figure.9 Working of TEG

4.0Experimental setup:

Peltier module was selected to work as generator. The heat input at the hot side is 160˚C and cold side of 30˚C. It was observed that the open circuit voltage at required 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 12 W module 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 cook stove. 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 cm3 thick aluminium block.

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 12 V module is very high as, but the individual voltage and current output was not sufficient as per our requirement. The voltage output of the 12 V is quite low and the **current is** very high

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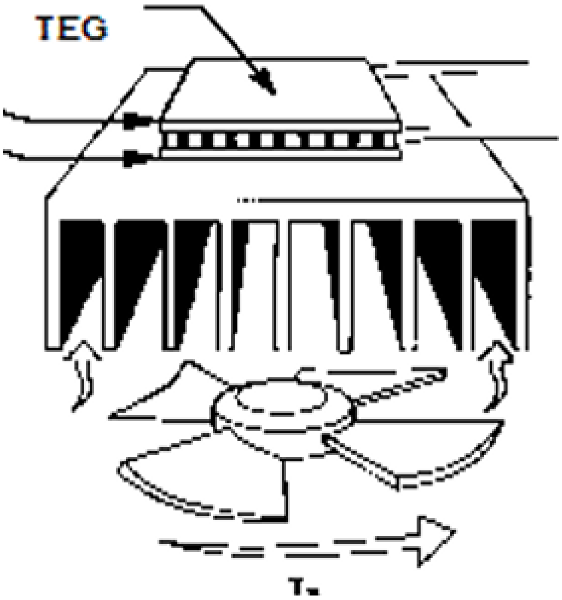

Figure 10 Setup for integrated TEG with fan and heat sink

The above figure10 shows the setup for one of the major part of the experimentation. Here thermoelectric generator is made to assembled with a DC fan and the heat sink.

Then the integrated part is made to assembled with the drum , which is used as the cook stove in our experimentation. The following figure shows the complete setup for the experiment.

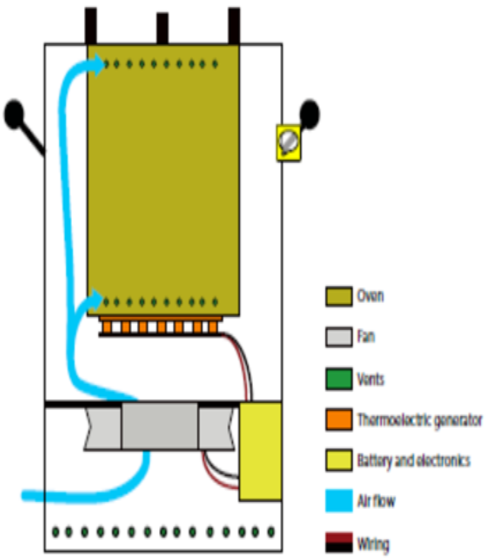

Fig.11 Complete setup for the experimentation

The below (figure12) is the complete setup for the experimentation in practical. The figure 8 shows the inverted setup. The TEG setup is assembled at the bottom of the cook stove for the better heat transfer. The wires may be covered with the silicon tubes if the temperature reaches high and can cause burning of the wires.

Figure 12 Drilled cylindrical drum stove

Fig.13 TEG module setup after the cooking or burning

The above figure13 shows the wiring of the setup. The wirings are done as per the requirements and then the output wires are connected to the DC-DC step up converter as shown in the figure 12. The main purpose of DC-DC step up converter is to enhance the voltage to 5 volts from 2.4 volts.

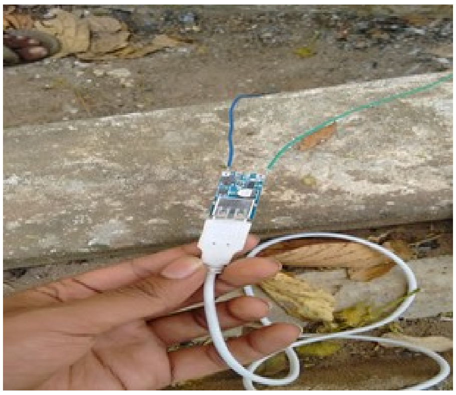

Figure.13 DC-DC step up converter

The DC-DC Step up converter has USB output , which can be connected to the mobile or any charging appliances to charge it at the same time during cooking. The figure 13 shows the charging mobile phone during the experimentation.

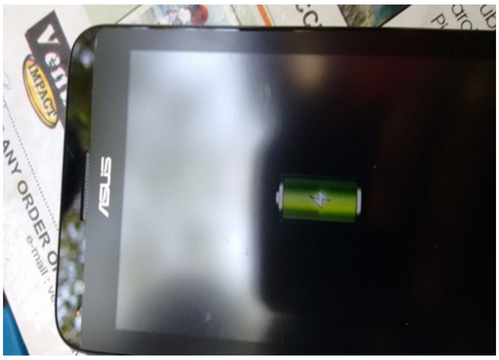

Fig.14 charging mobile phone during experimentation

5.0Performance Analysis:

Output of voltage at different temperature difference

This is a fact that the out of the thermoelectric generator purely depends on the temperature difference maintained at two different junctions. Accordingly the output voltage and current depends. More the temperature difference between cool and hot side will be , more the voltage will be generated. The following graph shows the variation of voltage at different temperatures:

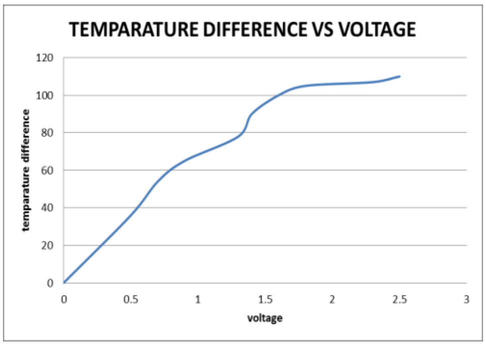

Figure.15 Voltages at different temperature differences

The following observations can be made from the above graph:
1.The maximum temperature difference maintained in the experiment was 110 degrees Celsius.
2.As the temperature difference kept on increasing also the voltage increased gradually.
3.The voltage was observed at different temperature difference during the experiment.
The maximum open circuit was noted and observed in the graph was 2.5 volts

Results obtained during experimentations

The following results were observed during experimentations:
1.Temperature difference :110 DEGREES
2.Open circuit voltage and current: 2.5 VOLTS,0.8 AMPS
3.Step up voltage : 5 VOLTS
Power required for charge the mobile 5 volts and 0.6mA

CONCLUSION:

This study describes the design of an energy efficient biomass cook stove for developing countries to accomplish the requirement for both, cook stoves itself and electricity generation. For a simple and low cost application of a rural cook stove, commercially available thermo electric modules are tested and the suitable module is determined for selection. The best power output of the system depends upon the difference in temperatures, through both sides of thermo electric module. A particular attention must be paid to the design of the heat exchangers for heat plate and cold sink. An idea about various parameters associated with the cook stove and TEG module can be viewed with the help of results represented in above graphs. This study shows how that the TE modules can be a used in cookstoves in convenient way. In this scenario the best generator module is required but the heat exchanger can be manufactured and assembled in a local workshop. The voltage generated from the modules practically is small due to inability to maintain the temperature difference, hence a dc-dc converter have to be connected to boost output up to the required voltage. The produced electricity will run the fan of the cookstove to increase the combustion efficiency. Thus it will decrease the fuel consumption and the emission level. A total voltage of 5 volts was generated. The total cost of the project was 2500 rupees for experimentation. Extra electricity generated can also be utilized to power up LEDs or charging a mobile phone.

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