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# Modeling of Low Cost Power Generation Unit from Waste Heat

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***ABSTRACT:*** *To cope up with the increasing power shortage crisis numerous attempts have been reported so far in reputed journals. But the ardent fact is that nearly 25% of the power is used as heat in actual practice and largely 75% power is wasted. The authors are keen to develop a low cost power generating model for exclusive use in rural India. A proposal for a prototype is being done here that is capable of generating power from waste heat using a TEM. The model is later analyzed regarding efficency and cost effectivity. The model is best suited for rural India but is also quite realistic for road side food stalls in cities like kolkata. The authors categorically compared the model with previous prototypes and the results are in good agreement.*
***Keywords –*** *power generation, thermoelectric module, seebeck effect, low cost.*

## I. INTRODUCTION

Energy supply and consumption has raised numerous challenges in the present day world [1]. The increase in global demand for oil has been recorded since long. Accordingly oil prices are getting high day by day and now it is a matter of open challenge. Such challenges require elegant solution. On the other hand, the effect-of greenhouse gases further raises the concern of global warming. Especially the effect of carbon dioxide is catastrophic on the environment. All these issues are omnipresent and are thus they are driving the demand for obtaining more useful energy usability. Numerous novel technologies that are in use and few more are under development. Contemporary research deals with the issues of vehicle transmission to increase transport vehicle fuel efficiency. Most of the energy produced is still being released as unused heat in the form of vehicle exhaust or the cooling system. In fact, in internal combustion engines, exhaust gas emissions accounts to over 40% [2] of the energy wastage, engine coolant absorbs nearly 30% of the energy, 5% loss can be credited to radiation & friction losses, whereas vehicle mobility and accessories deals with the remaining 25% of the energy as usable form. According to the current waste energy assessments in US alone energy equivalent of 46 billion gallons of gasoline is wasted annually from the exhaust pipes of 200 million light-duty vehicles. But the stiking fact is that still there is an ample dearth in this type of research vicinity.

Besides, Thermoelectric energy conversion can be achieved using a TEM (Thermoelectric module) module. It is rather simple in design and the reliability presents added advantages of not involving moving or complex parts; it is silent in operation, maintenance free and eco friendly. This article attributes the basic theory involving TEM and builds up a base model applying TEM principle of operation. Further computations are carried out to investigate the creditability of the model involving different approaches and an analytical study of the model based on the performance is also included in this reporting. The model could also be very well applied to deal with power supply issues related to road side food stalls in cities like Kolkata.

## II. THERMOELECTRIC THEORY

Thermoelectric modules [3,5] are devices which can convert temperature difference directly into electrical energy. The direct conversion of heat to electrical energy was first coined in 1820 by German scientist Thomas .JK. Seebeck. The thermoelectric modules working on Seebeck effect reported an efficiency of 5-10%. Thermoelectric elements are made of N-type and P-Type semiconductors that are connected by metallic interconnect. The current will flow across n-type to p-type element as shown in Fig 1. Every p-type and n-type are power generating unit and they are thermally in parallel and electrically in series. A total output is the series adding of the voltage of each semiconductor.

The Seebeck effect which is the primary phenomenon for power generation in a thermoelectric module is actually the sum of Peltier and Thomson effect.

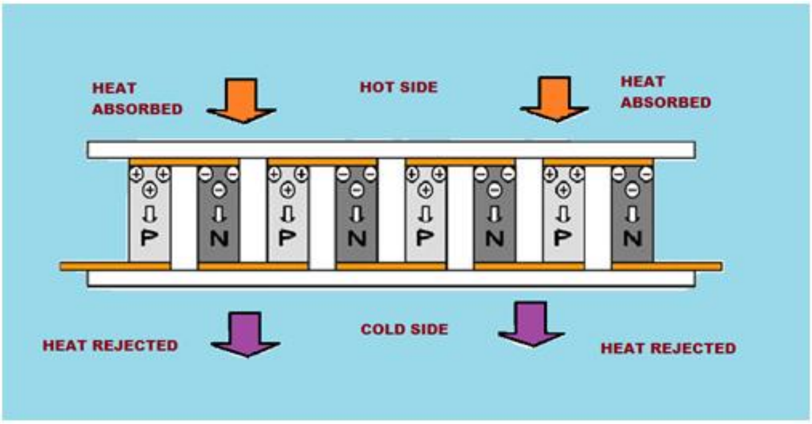


**Fig.1:** Working of a seebeck cell.

**Seebeck Effect**

The conductors are two unlike metals denoted as material A and material B. The intersection temperature at A is used as a indication and is maintained at a relatively cool temperature ($T_C$). The intersection temperature at B is used as temperature higher than temperature $T_C$. With heat applied to junction B, a voltage (Eout) will appear across terminals $T_1$ and $T_2$ and hence an electric current would flow incessantly in this closed circuit. This voltage known as the Seebeck EMF, can be expressed as $E_{in} = \alpha(T_H - T_C)$ [6].

**Peltier Effect**

Peltier discovered that there was an opposite phenomenon to the Seebeck Effect, whereby thermal energy could be absorbed at one unlike metal junction and discharged at the other junction when an electric current flowed within the closed circuit. The thermocouple circuit is customized to obtain a different arrangement that illustrates the Peltier Effect, an occurrence reverse that of the Seebeck Effect. If a voltage ($E_{in}$) is applied to terminals $T_1$ and $T_2$, an electrical current (I) will flow in the circuit. The current flow will result in, a slight cooling effect ($Q_C$) at thermocouple junction A' (where heat is absorbed), and a heating effect ($Q_H$) will occur at junction B' (where heat is expelled). Reversing the direction of current flow will result in reversing the effect of heating.. Joule heating, having a magnitude of [I2 x R] (where R is the electrical resistance), also occurs in the conductors as a result of current flow. This Joule heating effect acts in resistance to the Peltier Effect and causes a net reduction of the available cooling [7].

**Thomson Effect**

W.Thomson, who explained the association between the two phenomena, later issued a more inclusive explanation of the Seebeck and Peltier effects. When a conductor having a temperature gradient over its length carries electric current through it, heat will be either absorbed by or expelled from the conductor. The direction of both the electric current and temperature gradient decides whether heat will be absorbed or expelled . This occurrence is known as the Thomson Effect [8].

## III. RESULT AND PERFORMANCE ANALYSIS

Experimental observation:
Method 1- ambient temperature
Method 2 - chilled water
Method 3- chilled water with cooling fan

| Method | Current (amp) | Voltage (volt) | Difference in temperature(ΔT) | Power (W) |
|---|---|---|---|---|
| 1. | 0.72 | 2.326 | 76°C | 0.198 |
| 2. | 0.115 | 2.769 | 96°C | 0.229 |
| 3. | 0.112 | 2.932 | 98°C | 0.232 |

**Table 1:** Average data of TEC1-12706.

Temperature of heat source=104°c (saline water) Temperature of ambient=28°c Temperature of chilled water= 8°c Performance calculation:
Three motors running at 0.2W per motor and the cooling fan 26.4W.

Amount of heat transferred to the system= $\dot{Q} = \Delta T / (R_F + R_C)$

$R_F$ =Resistance in the fins $R_C$ =Resistance at the base

$R_C = t_h / (k \times A_H)$ =0.0248Ω k is thermal conductivity of thermal grease ( i.e.: zinc oxide )

$t_h$ =thickness of pas $t_e$ =0.1cm $A_h$= area of the paste application=40x40mm$^2$

$R_F = 1/\left(n \times h_f \times w_f \ (t_f + 2n_f l_f)\right)$ $l_f$ =length of the fin=22mm k=thermal conductivity of fin material=180 $w/mk$

$n_f = \tanh(ml_{c_l}) / ml_c$ =0.0272 $w_f$ =width of the base=59mm

$ml_c = \sqrt{(2h_f l_f)/(kt_f)}$ =36.648 n=no of fins=12 $h_f$ =convective heat transfer coefficient=5000w/m$^2$k

$R_F$ =0.134 Ω $\dot{Q}$ =497.481W

TOTAL POWER OBTAINED= $(0.2 \times 3) + 26.4 = 27W$

Therefore efficiency of the model= $27/497.481 = 5.427\% (Approx)$

In the above analysis the authors figure out that the last method is e best choice because of maintaining boundary conditions at the cold end fetched maximum output and hence it is evident that how much power can be generated depends largely on how well we maintain the temperature difference between two ends and also how efficiently we absorb heat at the hot end and release at the cold end. The design of heat sinks in this kind of a system is of outmost importance in order to get best results. Another important fact that needs to be mentioned here is that to get maximum efficiency, temperature difference is not the sole parameter, the load resistance and the module resistance have roles to play. It is theoretically observed that the module achieves highest efficiency only when the load resistance is equal to the module resistance. In the above discussion the value of heat supplied can be calculated more accurately by the following equation:

$$Q = N \times C[(Z \times T_C)/2 - (T_H - T_C)]$$

Where n is no of couples
Z is the figure of merit
$T_H$ & $T_C$ are respectively hot and cold side temperatures.
Here Z is given by $(Z) = (\alpha_P - \alpha_N)2 / R\ C$

Where individual seeback coefficient and conductance of thermoelectric elements of the modules needs to be taken into account which was beyond our scope in this investigation and hence such complications have been avoided throughout.

## III.1 APPLICATION CONCEPT

Biomass energy can be attributed for about 90% of the total rural supplies in rural areas of developing countries. Biomass combustion meets essential energy needs for cooking and heating in rural households and for heating process in traditional industries. In broad-spectrum, biomass is burnt through open fire stoves. These conventional stoves are characterized by low effectiveness which results in incompetent use of scarce Fuel-wood supplies. Biomass is a CO2-neutral renewable source of energy but conventional open fire stoves are known to lead to high emissions of health damaging air pollutant. To put aside wood fuel and spare rural communities from acute respiratory infection (ARI), it is important to replace a familiar rural open fire stove by an superior one.

Our concept design aims at renovating such domestic stoves in order to make it not only more efficient but also serve the purpose of generating electricity alongside cooking. This design can also be readily applied to renovate the existing LPG stoves used by most of the road side food stalls to generate their own power supply demand which will not only be more profitable for their individual business in the long run but also solve the problem of power theft which has been unsolved issue for quite some time in metro cities like Kolkata.

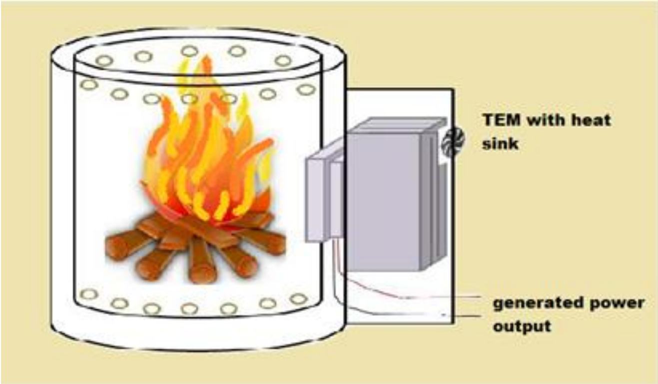


**Fig 2:** Schematic representation of prototype model.

**Performance analysis of application concept:**
**0.5 liter water**
Ambient temperature=25°c
Boiling temperature=100°c
Amount of energy required to boil the water from $25^{\circ}C$ to $100^{\circ}c = 75\times 0.5\times 4184J$
$= 157\,KJ$
Amount of energy supplied in actual practice by LPG cylinder to boil 0.5lt water over a copper pan=1.09MJ
Therefore system efficiency $= 157 \div (1.09\times 10^{3}) = 14.39\%$
Applied design (approximate efficiency improvement)
Power external to water heating obtained from TEC module=27W
Time taken to boil water = 6 min
Therefore external energy obtained= $27\times 360 = 9.72\,KJ$
Therefore new efficiency obtained= $(157+9.72)/(1.09\times 10^{3}) = 15.39\%$
Improvement of % = 0.90%

In this analysis we have just tried to predict the performance of a domestic stove in the process of boiling water as a subject of reference and does not involve actual experimental observations. Also we have considered LPG stove instead of cow dung for the ease of prediction, it is also evident that we have just considered our experimental model setup discussed earlier has been considered in addition while comparing the performance. Thus a module of much more capacity and much more efficiently designed heat sinks may be used in order to fetch much more relevant results which actually opens up the further scope of this project work and investigation.

## IV. MATERIALS AND MODEL SETUP

In this section we have briefly described the set up of our base model which has been the focus of our exploration. The different materials used in the set up of the model have been listed below with relevant specifications and detail

| **Material Name** | **Specifications** |
|---|---|
| Heat Sink<br>1) Aluminum Extrusion designed by Intel.<br>2) Normal heat sink. | Aluminum Extrusion Diameter – 9cm<br>Normal Heat Sink:- Length- 4.5cm, Breadth- 5.4cm, Thickness of fin- 0.91mm,<br>No. of fins- 12<br>Length of fin- 2.2cm Material- Aluminum<br>Thermal conductivity (K) – 120-240watt/m-k |
| Low voltage motors | RF- 300CA DC motors<br>Voltage- 3 volt max<br>RPM- 700<br>Current at no load- 0.018Ampere |
| Thermal grease | Compound – Zinc Oxide (K= 25.2 watt/m-k) |
| Thermo electric module | Model : TEC1-12706 |

**Table 2:** Specification of materials used in making of the prototype.

- **Cooling Fan from old CPU**
- **Plastic Fan Blade**
- **Ammeter**
- **Voltmeter**
- **Temperature Measuring Device**

According to the theory and principle governing thermoelectric effect the base model has been set up keeping in mind of all necessary precaution and guidelines. The two heat sinks are used as the heat receiving and heat liberating items to maintain the required temperature difference, the thermoelectric module a TEC in this case has been kept sandwiched between the two heat sinks. Thermal grease has been used at the interfaces in order to minimize the contact resistance. Primary heat source used in this case has been saline water at its boiling point kept in a tub. The use of saline water has been purposeful in order to attain max temperature at the hot end. An aluminum foil has been attached with the cold side sink in order to maintain different ambient condition during the whole investigation. Lastly general ammeter, voltmeter and temperature measuring devices have been used to record experimental results across the ends and finally a set of fans connected in parallel has been attached with the ends of the module to demonstrate the power generation.

**PROTO TYPE MODEL SETUP**:

**Fig 3:** Proto type model setup

## V. CONCLUSION

The authors here conclude that the basic model of power generation is not a very good option for generating power as it cannot match the efficiency of other available systems. On the other hand the proposed model is simple straight forward and robust in nature in places where efficiency is not the matter of concern likes space application etc., and where design considerations are major parameters only. Further this system can readily be applied to already existing system in order to make it greener or increase its area of applicability. In this regard this idea requires much attention and there is plenty of experimental investigation scope in this regard.

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