A Review on Generation of Electricity using Peltier Module

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***Abstract*—As the dawn breaks, every day we come across some new technology or development in the field of science. The scope of this wide spectrum in which humans are encouraged to find a better substitute for the older technologies has made so many advancements to make day-to-day life easy. One such major point of focus today is to replace the electricity with the non conventional energy resource-harvesting methods. In the same way, heat can be a good source to produce power from it. The principle of Seebeck effect can be used for such applications. It was first described as long ago in 1820 by a German physicist - Thomas Seebeck. Two metals with a common contact point, where the potential is developed due to the temperature difference in the other two ends of metals, is all about Seebeck effect. Peltier module also follows the same principle. We have used TEC-12706 in our experimentations to know ways to optimise the use of a Peltier module. This review paper shows that heat harvested from different heat sources generate different amount of voltages and overall power. Experimentations also showed that using different ways to extract heat from the other side of the module made output voltage to vary accordingly.**

Keywords—Seebeck effect; Peltier effect; Thermoelectric; Energy Harvesting;

I. INTRODUCTION

Energy harvesting is the main focus of the researchers all over the world. It is because of deployment of million sensor nodes and bottleneck of battery. This method avails various transduction methods like piezoelectric, electromagnetic, solar and thermoelectric [1][2].

About two-third of the energy generated by a conventional power station is actually lost in the form of waste heat that escapes out of a cooling tower. Part of the problem is the gas or steam powered turbine systems that we use to produce most of our electricity work upon first burning of fuel to produce heat energy and converting the heat energy into mechanical energy and turning the turbine, and converting the mechanical energy into generator. This process is intrinsically wasteful, only about one third of the energy unleashed from the fuel actually ends up in the wire leaving the power station. But if we could mop up the wasted heat and could convert it into usable electricity, this would make the power generation much more efficient. And this in turn would be best or the environment, because we would need to burn less fuel and less CO_2 emmision. This is where Thermoelectric Generators or TEGs come in. These are devices that can convert heat energy directly into electrical energy without any need for moving parts or turbines [3].

II. THERMOELECTRIC MODEL DESCRIPTION

A thermoelectric device is a solid-state semiconductor based electronic component capable of converting a voltage input into a temperature difference which can be used for either heating or cooling. Conversely, when a temperature difference is applied to the device, it has the capability of producing DC electrical power. Ceramic substrate is made of Alumina, Beryllium Oxide or Aluminium Nitride. Diffusion barrier is layered on the ends of each element. Copper interconnects are given on ceramic to let the current flow from each couple through links.

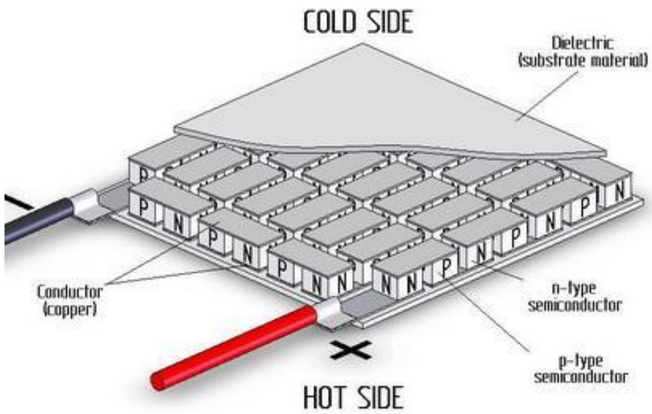

Figure 1. Internal view of a TEG [4]

Thermoelectric Generators work by exploiting a temperature gradient between the two sides of the generator. Think of it like this, take a piece of metal, heat one end and simultaneously cool the other. The electrons surrounding the metal atoms at the hot end will have more energy than the electrons on the cooler end. This means that the hot electrons will be jiggling around faster than that on the cool end, and they'll tend to move faster towards the cold end faster than the cold electrons will move towards the hot end. Eventually, the cold end will become more negatively charged, and the hot end will become positively charged. This phenomenon where a temperature difference can create a voltage is called the thermoelectric effect. So it sounds simple, but one big problem is that the voltage produce is absolutely tiny. This can't just be solved by connecting lots of pieces of metal together in series like you would do to make a bigger battery because the wires used to connect them which are also pieces of metal will produce a voltage in the wrong direction and oppose the voltages in the pieces of metal.

The way that scientists have solved this problem is by using a material that can conduct electricity using positively charged particles rather than electrons. Just like the electrons in the metal, the positively charged particles will move away from the hot side. So now if you link a chain of them together, the voltages will add up along the series allowing us to generate a useful amount of power. Materials with this type of positive conducting property are called semiconductors. And in fact, rather than heating pieces of metal to create the current another type of semiconductor material which conducts using electrons and is much more efficient generator is used instead, sandwiched between the two positive conducting semiconductors.

Another problem with thermoelectric devices is the types of material that allow electrons to flow easily. So we can tap off the electricity also tend to be very good at conducting heat. So very quickly the temperature gradient driving the process is lost and the efficiency falls. To get around this, scientists are trying to find materials with a high electrical conductivity, but a low thermal conductivity [5]. One way to achieve is to use metal alloys which can be used to form some lattice of different sized atoms to slow down the flow of heat or allowing the electrons to move freely. In the same way, certain arrangements of nano-particles can trap heat and slow it down. In general, the more joints and interfaces there are between the particles, the slower heat is able to move.

II. THERMOELECTRIC OPERATING MODES

There are three modes of operation as listed.

A. Cooling mode
B. Heating mode
C. Power Generation mode

- Cooling mode

Alternating P and N type TE elements are wired electrically in series, and thermally in parallel. As the current passes through semiconductor elements, Peltier cooling lowers the temperature of the TEC cold side [6,7].

- Heating mode

Reverse the polarity of the current. The previously hot side starts to cool and the cooler side now acts as the hot surface [8].

- Power Generation mode

When a temperature difference is imposed across the device by adding an external heat source, the heat passing through the device is converted to electrical power. As the heat travels, power through the device is created. As the temperature difference increases, power output also increases.

IV. THERMOELECTRIC DEVELOPMENT

A. *Figure of merit*

One of the important factor to consider for the efficient output of the Thermoelectric device is the figure of merit ZT.

$$ZT = \frac{\alpha^2 \sigma}{\lambda} T$$

Where, α= Seebeck coefficient
σ = Electrical conductivity
λ= Thermal conductivity

While measuring the voltage difference between the two terminals, the junctions of two dissimilar conductors is maintained at two different temperatures [9-11]. Let the temperature difference be given by $\Delta T = T_H - T_C$, where T_H and T_C are the temperatures at hot and cold surfaces of the module respectively. The Seebeck coefficients of the p-type and n-type semiconductor be α_p and α_n respectively.

So, the Seebeck open circuit voltage can be given as

$$V_{open} = (\alpha_p - \alpha_n)\, \Delta T$$

B. *Efficiency*

Good semiconductors have electrical conductivity in the range of 200 µV/K-300 µV/K. Also thermal conductivity plays a major role in the efficiency of a thermoelectric device [12]. Materials having thermal conductivity of range 1W/m.K-1.5W/m.K are found to be having good figure of merit also, which in turn contribute directly to the efficiency of the device.

C. *Effect of Temperature gradient*

Fankai Meng, Lingen Chen et al. [13] describe the effect of temperature dependence by obtaining the heat conduction differential equations of P-Type and N-Type semiconductor. To understand it more deeply, we can go through the graphical representation of temperature dependence on power and efficiency shown by D. C. Talele, et al. in Figure 3,4 in his paper [14].

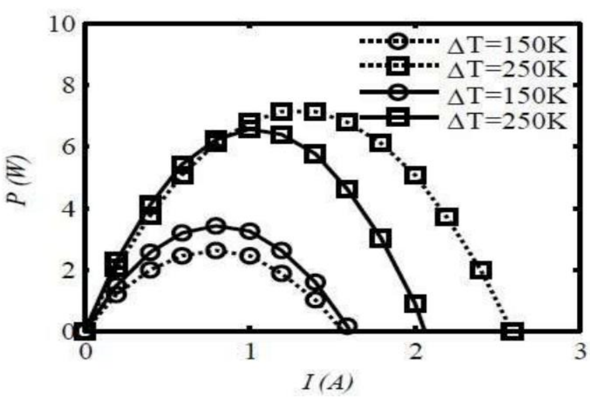

Figure 2. Effect of temperature dependence on power versus electrical current [5]

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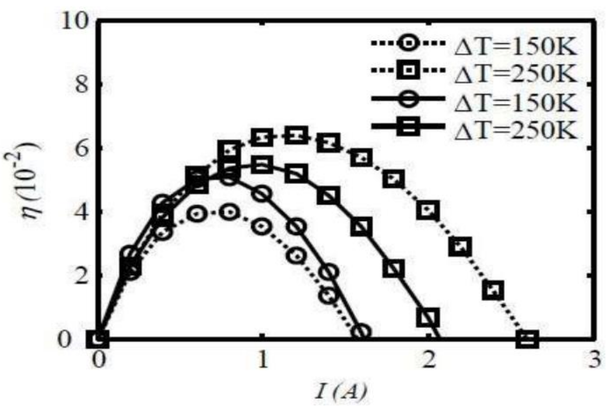

Figure 3. Effect of temperature dependence on efficiency versus electrical current [5]

V. THERMOELECTRIC APPLICATIONS

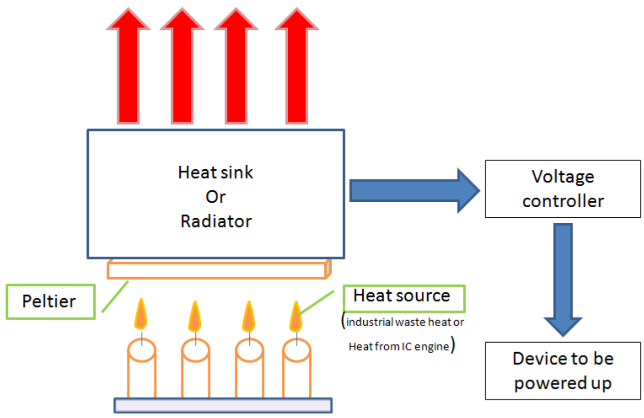

Figure 4. Block Diagram of Thermoelectric Power Generation System

Figure 4 reveals Thermoelectric Generation Set-up. A large amount of waste heat from industries remains unutilised. So it can be a good energy source to generate power.

A. Industrial waste heat recovery

Different cooling methods that do not need an external power supply to extract heat from the heat sink were reviewed and experimented [15-20].We have this simple demonstration set-up. Since the industrial waste heat is in huge amount, we have used candles to demonstrate this heat as the source Heat is applied to one side of this thermoelectric device and causes electrons to flow through the completed circuit which results in enough power to energise the LED.

Phenomenon of power generation is made possible by creating a temperature difference across two surfaces of the thermoelectric device much like in electrical generation that results from the movement of a magnetic field across the conductor, it's the movement of the heat that causes the electrons to move just as when the magnetic field ceases to move electron flow stops when the heat ceases to move the electron flow stops.

B. Heat recovery from Internal Combustion Engine

We used the heat from the exhaust pipe of the automobile as the heat source. One side of the module was kept in contact with the exhaust pipe, and the other side it had the pure aluminium heat sink which was cooled with a free spinning mechanical fan (No electricity fan). This setup was mounted on the vehicle. As the vehicle moves, exhaust pipe starts to heat up and reach near to 150°C. This provides a good temperature gradient of about 70-80°C, thereby giving the enough output power to run small devices.

Sr. No .	Heat source	Temperature of hot surface T_H(°C)	Temperature of cooler surface T_C (°C)	ΔT (°C)	Voltage produce d by module
1	Industrial waste heat	150	70	80	3.05 V
2	Heat from vehicles	135	68	67	2.68 V

Table 1. Output voltages for different heat source

Recently, TEGs produced by using these technologies are only about 10% efficient at best. But in industries on the scale of a power station, even at this early stage, this could still contribute a huge fuel saving. Another area that might seem benefit from this technology is the auto industry. Just like a power plant over 70% of the energy locked up in the fuel you put up in the car exits along the exhaust pipe has wasted heat. As a result a number of car manufacturers are now testing prototype TEGs that can scavenge back some of this wasted heat from the exhaust and use it to run things like the lights or to charge the batteries in hybrid vehicles. Industry experts are predicting that will see the first mainstream tag equipped cars as soon as 2020.

But there is one place where TEGs are already proving their worth- Space Exploration. Particularly aboard probes going so far away that solar power isn't an option. Space provides an excellent working environment for TEGs, because the average temperature in space is just 3 degrees above absolute zero which takes care of the cold side of the generative very nicely. Meanwhile the hot side is provided by a radioactive source such as strontium-90 which produces the heat as it decays. This type of radio-isotope TEG was used in the Apollo missions and is currently powering the Cassini and Voyager spacecraft missions millions of miles from home.

VI. COST CONSIDERATIONS

A. Jacks, Delightus Peter showed that the performance of the module shows versatility in applications. TEG (thermoelectric generator) works on the principle of Seebeck effect, while TEC (thermoelectric cooler) works on its converse principle, i.e. Peltier effect.

Similarly, their applications also differ as per their working. The TEGs are mainly made up of Bismuth Telluride or Lead Telluride. But both differ in properties like heat withstanding capacity and efficiency. Bi_2Te_3 TEG is high efficient but cannot withstand the heat as much as PbTe can. So, cost variation occurs due to these properties [21].

Gou X, Xiao H has focused on the modelling of TEG. TEGs integrated in bulk produce the highest output power and voltage. It easily produces sufficient power at a high enough voltage to power a variety of low power sensors even when harvesting energy from the temperature differences as low as 5°C. So, as the number of modules increases, the cost of the system also increases. Also, the µTEGs are more efficient for applications used acquisition of electrical energy at the high temperature difference due to their size considerations and the compostion material. Different combinations of series and parallel connections are arranged to achieve sufficient power [22-23].

Sarinee et al. Reveals that the voltage increases 2 to 4 times when the modules are connected in series, and the current is not much affected [3].

TECHNOLOGY BENEFITS

The following technology benefits can be availed while designing TEG based energy generator.

- Solid state construction(no moving parts)
- Diffusion barriers (standard in all MI devices) enable superior long term thermal stability and high reliability.
- Precise temperature control.
- Vibration-free operation.
- Chloro-fluoro-carbon free, for applications where gases are not permitted.
- No acoustical or electrical noise.
- Performs in any physical or gravitational orientation, including upside down or sideways.
- Operates in zero gravity.
- Withstands the high G-force of space and military applications.
- Size and performance output highly scalable.

VII. CONCLUSION

Thermoelectric devices are an advantage over the conventional resources despite of their low efficiency. Moreover, their versatility in application of cooling and power generation also makes them considerable over electrically powered devices. Since the voltage obtained from a thermoelectric generator is tiny, certain combinations of modules in series and parallel make the power generation comparatively efficient. Coming to the cost considerations, the thermoelectrics are costlier than the other power generating techniques, but one can always trade off between the cost and the conventional energy resources. Our prototype generates 3.05 volts and 2.68 volts from industrial waste heat and automobiles respectively.

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