DESIGN AND CONSTRUCTION OF THERMOELECTRIC GENERATOR USING PARABOLIC TROUGH COLLECTOR

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ABSTRACT
The use of thermoelectric generators (TEGs) to convert solar radiation into electrical energy and capture waste heat from the sun has brought attention to the need to reduce carbon emissions and balance the energy supply and demand. Thomas Johann Seebeck discovered in 1821 that electricity can be generated by a temperature gradient that forms between two different conductors. The diffusion of charge carriers is caused by heat flow, which is the fundamental mechanism underlying the thermoelectric effect in conducting materials. In turn, the movement of charge carriers between the hot and cool areas produces a voltage differential. A thermoelectric generator (TEG), or a Seebeck generator, is a solid-state device that uses the Seebeck effect to directly convert heat flow, or temperature differential, into electrical energy. This experimentation on the design and construction of a 1kW thermoelectric generator using solar energy with a parabolic trough collector is composed of a parabolic trough collector framed from a plain mirror with an aperture area of m 0.27m2 that was used to concentrate sunlight onto a copper receiver plate with an area of 10×10 cm^2. A power of 0.9kW was achieved by connecting 7 numbers of thermoelectric modules (TEM) generating 2.4V and 469 mA at an average temperature gradient of 60^{o}C.

Keywords: Thermoelectric-generator, Seebeck-effect, Conductor, Thermoelectric-module, Temperature-gradient.

1.0 INTRODUCTION

In light of the current global energy crisis, energy harvesting is essential. The available energy can meet the majority of the world's energy needs, but they originate from non-renewable sources (Dresselhaus and Thomas, 2001). The non-renewable energy sources known as fossil fuels are running out quickly since the amount of energy consumed by each person is rising daily. Furthermore, one of the main causes of the issue is population expansion (Lertsatitthanakorn et al., 2012). Fossil fuel days are limited and fast diminishing in deposits around the planet and alternate forms of energy production have to be researched (Shafiee & Topal, 2009) .

It is imperative to find a way to capture energy and convert it efficiently without risking the depletion of other resources. More than just being a non-renewable energy source, the fundamental issue with fossil fuels has always been their extreme pollution and global warming (Midilli, 2006). As a result, green energy options need to be carefully studied.

According to (Hassen, 2000) the remedy is to manage energy efficiently to resolve these lingering issues. Given the current environmental problem and the world's energy needs, a gradual and seamless shift to green energy is essential. There is nothing more alluring than the idea, development, and application of a plentiful, easily accessible green energy source. Thermal energy has several benefits and is a very appealing energy source (Heremans, 2002). Waste thermal energy from industrial processes, automobile exhaust, and residential heating is constantly present (Snyder and Toberer, 2008). If the temperature differential in the environment is effectively captured, energy harvesting may result.

Thermo-electrics is the study of the transformation of thermal energy into electrical energy and vice versa (Goldsmid, 2009). The initial discovery of this phenomenon was made by Seebeck in the year 1821. The idea of using the temperature differential between two surfaces to produce energy, known as the Seebeck effect, has great promise as a clean, alternative energy source. Although this idea has been around since the turn of the century, it has recently received a lot of attention (Dresselhaus , 2007).

Despite these devices' limited efficacy and high cost, thermoelectrics is a field that is revolutionizing energy gathering due to its many advantages over conventional approaches. Green energy comes from thermoelectric devices. They have no moving parts, emit no emissions, and make no byproducts when they operate, equally, they do not generate noise during operation (Poudel, 2007).

If this technology is to be implemented, many of the frequent questions that need to be answered include no maintenance, high reliability, and long lifespan. All of these criteria are partially addressed by thermoelectric devices now on the market.

The ability to manufacture large and small devices with thermoelectric technology is another huge benefit. These devices have a significant impact, particularly in this era of nanotechnology. By utilizing the Peltier or Seebeck effects, respectively, thermoelectrics can be utilized to control temperature or to generate electricity.

1.1 SEEBECK EFFECT

It was believed until recently that Thomas Seebeck made the discovery of the Seebeck effect. It is currently believed that Alessandro Volta discovered the Seebeck effect 27 years before Thomas Seebeck (Pastorina, 2009). In 1794, Alessandro Volta performed experiments in which he formed a u shape out of an iron rod. One end of the rod was immersed in hot water to heat it up. The muscles of a dead frog leg flexed when a current was run through it via an electrical connection to the unevenly heated rod. This is thought to be the first instance of the Seebeck effect being demonstrated.

Thomas Johann Seebeck made the new discovery that electricity can be generated by a temperature gradient that forms between two dissimilar conductors in 1821. The diffusion of charge carriers is caused by heat flow, which is the fundamental mechanism underlying the thermoelectric effect in conducting materials. In turn, the movement of charge carriers between the hot and cool areas produces a voltage differential. (Baranowski et al., 2013)

When two dissimilar metals, A and B, are linked, a temperature differential between the junctions (J1 and J2) causes a net voltage to be generated (Figure 1). One connection will be hotter than the other since it is heated to a higher degree than the other.

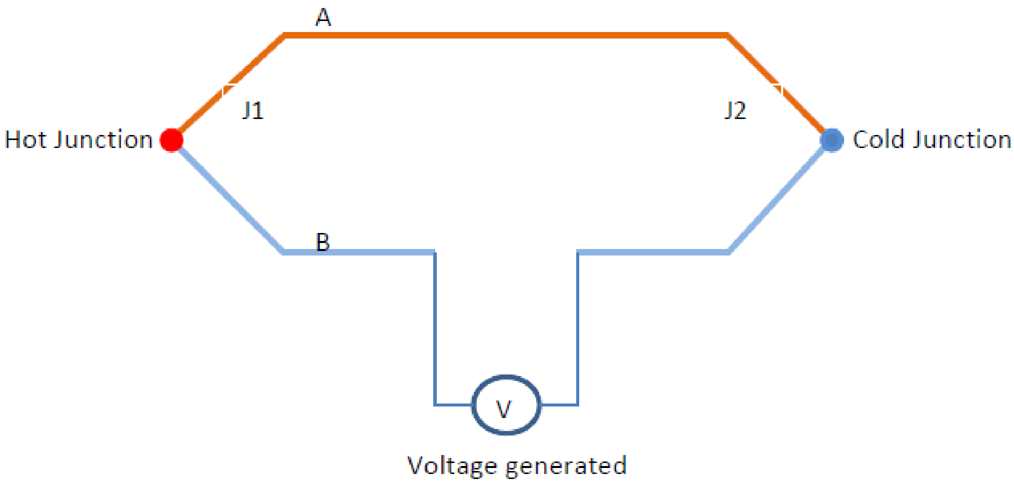

Figure 1: Seebeck effect using dissimilar metal junctions

An additional characteristic of distinct bulk materials is the Seebeck effect. This idea serves as both the foundation for power generation and a means of measuring temperatures. The Seebeck coefficient, or the voltage generated by the temperature gradient divided by the temperature difference, is given by equation 1.

$$S = -\frac{dV}{dT} \qquad (1)$$

where, S – coefficient of Seebeck, V is voltage and dT is change in temperature

Although the Seebeck coefficient is measured in volts per degree, it is more frequently expressed in micro-volts per degree Kelvin (μV/K). The sign of S is positive for p-type materials and negative for n-type materials.

1.2 PELTIER EFFECT

The Seebeck coefficient is commonly stated in micro-volts per degree Kelvin (μV/K), even though it is measured in volts per degree. For p-type materials, the sign of S is positive; for n-type materials, it is negative.

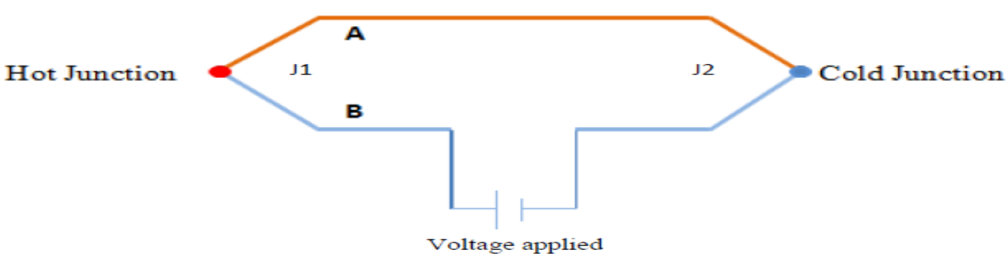

Figure 2: Effect Peltier

The Peltier effect is used in thermoelectric refrigerators, heated automobile seats, and cooling systems in electronics. The Peltier effect is used by thermoelectric devices to cool computer microchips and processors that generate a lot of heat over long periods of time.

1.3 THERMOELECTRIC MATERIALS

Thermoelectric materials convert temperature changes into electric voltage, allowing them to directly convert heat into electricity. These materials must have high electrical conductivity (σ) and low heat conductivity (κ) in order to be deemed suitable thermoelectric materials.Due to poor thermal conductivity, when one side is heated, the other stays cold, which helps create a high voltage in a temperature gradient. The amount that electron flow varies in response to a temperature differential across a material is indicated by the Seebeck coefficient (S) (Dresselhaus , 2007).

1.4 THERMOELECTRIC MODULES

A thermoelectric module is a circuit that uses thermoelectric components, or materials that directly convert heat into electricity. Two distinct thermoelectric materials, an n-type semiconductor (which has negative charge carriers) and a p-type semiconductor (which has positive charge carriers), are connected at their ends to create a thermoelectric module. Direct electric current flows through the circuit when there is a temperature difference between the ends of the materials. (Lertsatitthanakorn et al., 2012)

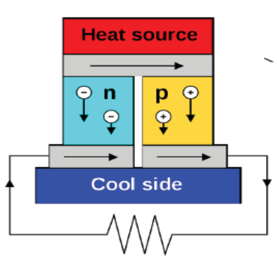

Figure 3: Electric circuit of Thermoelectric

In power generation applications, thermoelectric modules are utilized since they have to function in harsh mechanical and temperature environments. Since the modules operate in an exceptionally high temperature gradient, they are subjected to severe thermally produced stresses and strains over lengthy periods of time. Additionally, a lot of heat cycles might create mechanical wear in them.

In order for the joints and materials to withstand these extreme mechanical and thermal stresses, careful selection is required. Additionally, the two thermoelectric materials need to be positioned in the module such that they are thermally coupled in parallel yet electrically connected in series. The geometry of a thermoelectric module's design has a big impact on how efficient it is.

Thermoelectric Generator Using Parabolic Trough Mirror as a Collector

The parabolic trough mirror has several purposes, but its main one is to collect solar energy from a large surface area and focus it into a smaller area. For best results and economic output, the focal length of the parabolic trough mirror must be determined. The intersection of all the rays is the focus point, and it is there that the most heat is generated (Dresselhaus, 2007).

A parabolic trough mirror's focal length is located in the middle of its diameter and at a certain distance from the mirror's surface. The focal length (20) can be calculated using the formula (2). As seen in Figure 4, focal length is indicated by f, mirror depth is represented by d, and mirror diameter is indicated by D.

$$F = \frac{D2}{(4*4)d} \quad (2)$$

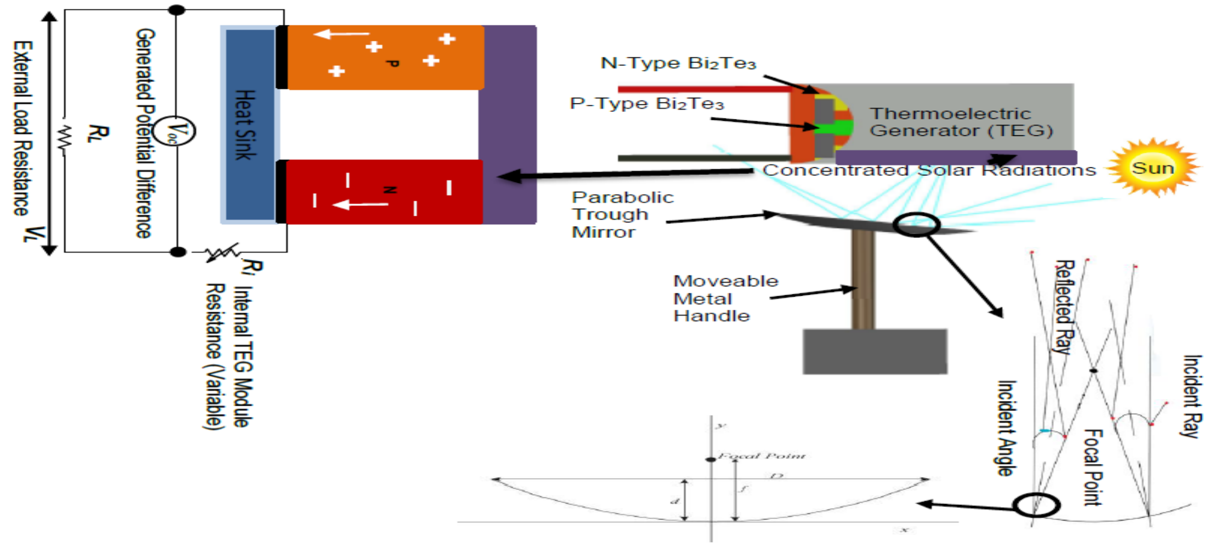

Figure 4: Illustration of a Parabolic Mirror with a Concentrator

A parabolic mirror's focal point is where the reflected rays converge when an incident ray strikes it (Figure 4). As a result, all of the reflected light passes through the focus point and concentrates there, where the mirror's maximum temperature is gathered for application to the TEG's hot side. Because the focal length lies on the focal axis of the mirror, all parallel rays that arrive at its surface are reflected and pass through the focus point. There is equality between the angles of incidence and reflection (Snyder and Toberer, 2008)

Solar Collector Types

Many types of solar collectors are used to collect solar energy. Experimental investigations relevant to altering elements such as the working medium, surrounds, and size are taken into consideration in order to optimize the design (Goldsmid, 2009). Analysis of energy has been done on several kinds of solar collectors. The majority of them were in the area of solar collectors using flat plates. The second most popular field of research concerned hybrid thermal and photovoltaic collectors. Additionally, a few investigations on evacuated tube collectors and parabolic trough collectors have been conducted. Numerous researchers have examined and refined parabolic dish collectors, demonstrating their excellent energy efficiency. Compound parabolic collectors, heat pipe collectors, and hollow receivers are other collector forms that are not as frequently studied (Midilli, 2006).

This study is aimed at the design and construction of a 1kW Thermoelectric generator using a parabolic trough collector.

Figure 5: Photograph of Parabolic Trough Collector

2.0 METHODOLOGY

A model of a parabolic trough solar collector was created and evaluated. The design consists of a hardwood support frame, copper sheeting for the system, glass strips for the reflector sheet, and galvanized sheeting for solar radiation absorption.

Dimension Parabolic Trough Collector

Simple parabolic equations were utilized in the collector's design. The aperture width (W) of the system is 0.65 meters, and the focal length (f) is 0.88 meters from the vertex (V) according to the reflector's design. The Cartesian equation for the design system was derived from equation (3) below (Handayani & Ariyanti, 2012).

$$X^2=4fy \qquad (3)$$

Equation (4) below was used to determine the height of the parabola in terms of the focal length and aperture diameter..

$$hc = \frac{w2}{16f} \qquad (4)$$

$$Tan\frac{\Psi rim}{2} = \frac{W}{4f} \qquad (5)$$

Where Ψrim is the angle of the rim

Figures 6 and 7 illustrate how the cross section for the parabolic trough was created utilizing a geometrical relation of the parabolic section. The parabolic trough, which has an effective aperture area of 0.2711 square meters and measures 1.844 meters in length and 0.50 meters in aperture width, was made using sheets of planar mirror. The values of the aperture area, curve surface area, focal length, parabola height, aperture width, receiver outer diameter, and concentrator length were determined using the above equations. The collector height hc and the focal length f are nearly equivalent. The manufactured system's specifications are listed below.

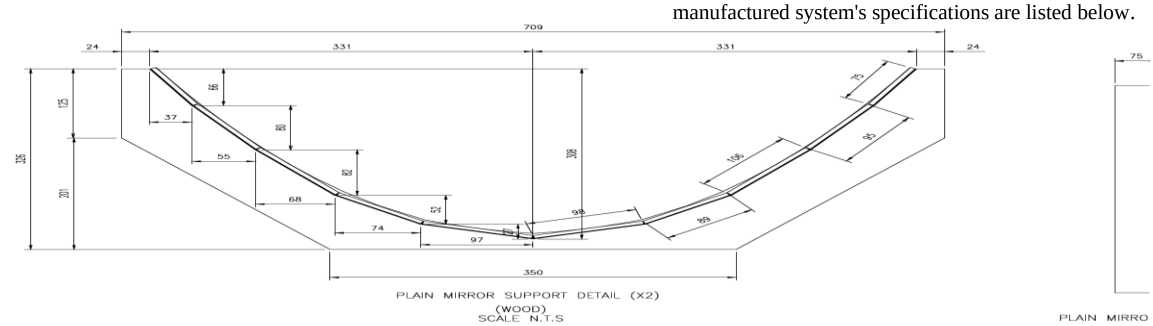

Figure 6: Drawing of produced Parabolic Trough

Figure 7: Produced Parabolic Trough Collector

Table 1: Specifications for the produced Parabolic Trough Collector

Constraint	Identity	Result
Aperture area (m2)	Aa	0.2711
Length (m)	L	1.844
Curve area (m2)	As	1.3655
Focal length	F	0.88

Numerical Approach employed in predicting the Electrical Potential of the TEG Under Use

The output electrical power of the thermoelectric module (TEM) increases with the temperature differential between its focused solar-heated hot side and cold side.
(Saim et al., 2020). To keep one side colder than the other, an efficient cooling system was needed because the temperature differential is difficult to achieve. The greater temperature differential indicates a relatively low total efficiency for the TEG. Thermoelectric materials are mostly responsible for setting the working temperature range of the device, and a rise in overall efficiency is largely dependent upon them. This range is often classified into three categories: The base of commercial TEGs is Bismuth (Bi) composite with Tellurium (Te), Antimony (Sb), and/or Selenium (Se) for less than 450K; lead (Pb) and Telluride (Te)

composites for 600K-850K; and germanium (Ge) and silicon (Si) composites for 900K-1300K (Saim et al, 2020).
Because of its appropriate working temperature range of <450 K, Bi2Te3-based TEG is used. They are frequently packed between heat-conductive components and connected in series to achieve appropriate power, providing heat from the concentrated solar heated source and cooling from the heat sink.

Experimental Procedure

TEG (SP1848-27145), measuring 40 mm by 40 mm by 3.4 mm, was utilized in these studies. It had both P and N-type elements (Bi2Te3), which were coupled to copper lead and insulated with Teflon. To find the right process for converting focused radiation into electrical power, several tests were carried out. To prevent thermal damage to the TEG from heat applied directly to its hot side and to reduce heat loss by reflection, a heat-resistant (220°C) black paint was applied to a flat metal connected to the TEG after it had been polished with sandpaper. During the first testing, a modest cooling fan was employed to support the hot plate with an external heat sink to keep the cold side temperature below 308 K (Dresselhaus, 2007). The hot plate can reach temperatures of up to 419 K, and its electrical performance was evaluated in a range of thermo-electrical scenarios. A heat-resistant (220°C) black paint was applied to a flat metal connected to the TEG after it had been polished with sandpaper. During the first testing, a modest cooling fan was employed to support the hot plate with an external heat sink to keep the cold side temperature below 308 K (Dresselhaus, 2007). The hot plate can reach temperatures of up to 419 K, and its electrical performance was evaluated in a range of thermo-electrical scenarios. The open-circuit voltage (Voc) test is carried out if the circuit is not linked to an external load resistor (RL). The short-circuit current test was performed after shorting the output leads with a copper conductor. When RL=Re, the maximum power performance was measured using a variable resistor of 100 Ω, and the TEG leads were connected to the external load resistor (RL) for the full-load test. The digital multimeter was used in these initial tests to examine the hot and cold sides of the TEG by connecting it to its input leads (Baranowski et al., 2013). A negative voltage measurement indicated the chilly side and a positive voltage reading indicated the heated side. In this way, the hot and cold sides of TEG are distinguished. Once the sides are identified, thermal glue is used to attach the TEG to the black-coated surface, with the hot side facing the surface that will be exposed to high heat. Once a fan and heat sink are attached to the cold side of the TEG to maintain its cool, it is prepared for experiments.

3.0 RESULTS AND DISCUSSION

Performance evaluation was carried out on the produced Thermoelectric Generator in order to ascertain its efficiency and effectiveness. The results of the readings generated for two consecutive days are shown in Tables 2, 3 and Figure 8, respectively.

Table 2: Results for a test carried out on day 1

Cold Temperature (ºC)	Hot Temperature (ºC)	Temperature Gradient (ºC)	Voltage (V)
24	44	20	0.97
37	77	40	1.8
40	100	60	2.4
42	122	80	3.6
50	150	100	4.8

Table 2: Result of tests carried out on day 2

Cold Temperature (ºC)	Hot Temperature (ºC)	Temperature Difference (ºC)	Voltage(ºC)
22	43	21	1.02
38	80	42	1.89
40	105	65	2.6
43	132	89	4.00
48	153	105	5.04

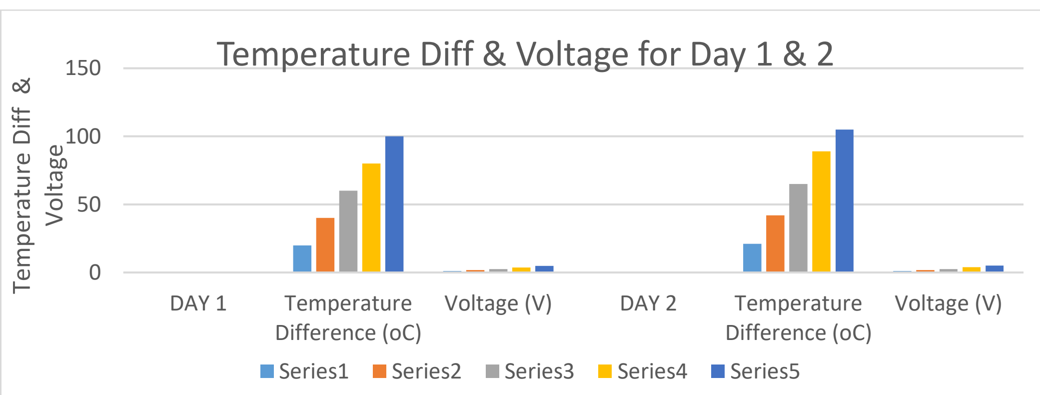

Figure 8: Graph of Temperature Difference and Voltage for Day 1 and 2

3.1 DISCUSSION

Based on the outcome attained for each increase in the temperature differential between the hot and cold sides. This illustrates that voltage exchange increases with thermal energy production. Therefore, this analogy can be used as a model for converting thermal energy into additional electrical power. The Seebeck effect applies the first law of thermodynamics to charging devices by converting temperature difference into voltage supply. The test conducted on the first day yielded a maximum temperature of 150°C for hot temperatures and 50°C for cold temperatures, respectively, at a voltage of 4.8V. However, the results of the test conducted on day two show that the maximum temperature at 5.04V was 153°C for hot temperatures and 48°C for cold temperatures.

4.0 CONCLUSION

A thermoelectric generator using Parabolic Trough Collector was designed and constructed. The constructed generator produces 2.4 V and 469 mA at an average temperature of 60ºC. More so, an average of 0.9kW of power was produced by the constructed thermoelectric generator.

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