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Thermoelectric Power Generation By Using Solar Parabolic Trough Reflector

Sravan Kasireddy*, Dr. V.Venugopal Reddy,**
**(M.TECH(PTPG) Student, Department of Mechanical Engineering, JNTUACEP, Pulivendula, A.P. sra1kasireddy@gmail.com)*
***Professor and H.O.D, Department of Mechanical Engineering, JNTUACEP, Pulivendula, A.P. vgreddy7@rediff.com)*

ABSTRACT: In the present rapidly developing world, generation and consumption of electrical energy playing an important role without harming the nature of the environment. To achieve the environment-friendly electrical power generation a lot of research was done and succeeded with technologies such as photovoltaic, concentrated solar power, wind energy, tidal energy...etc. This work is attempting a new way to convert solar energy into electrical energy by using a series of Thermocouples and parabolic trough reflector. Series of Thermocouples contain a number of hot and cold Junctions. Thermocouple hot junctions were arranged at the focal point of parabolic trough reflector whereas cold junctions insulated with some thermal insulation to reduce heat transfer. Parabolic trough reflector concentrates solar radiation at thermocouple hot junctions; this increases intensity of radiation due to this temperature of hot junction increases. Cold junctions are maintained at low temperature by using an external cooling medium. The temperature difference between hot and cold junction induces an e.m.f in series of thermocouples. Voltage and current generated during the experiment is measured by using a multimeter. In this work, results were taken for different Thermocouple materials with the different parabolic reflective surface combinations. Some suggestions are also made for improving the system performance.

***Keywords**:* Solar Energy, Parabolic Trough Reflectors, Thermocouple Materials.

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I. INTRODUCTION

Even though a large amount of solar energy is available on the earth surface, only a small portion of it is used for human activities. Presently only a 0.015% of solar energy is used for world electric power production, and 0.3% of solar energy is used for heating of space and water. Low usage of solar power is due to less energy conversion efficiency, the high cost of materials, energy storage and power distribution. A lot of research is done and still continuing to overcome above difficulties. In this work, a new attempt is made to convert solar energy into electrical energy by using a series of thermocouples and parabolic reflector.

Parabolic trough surface concentrates all incoming solar radiation at its Focal Point. Parabolic trough surface is best suitable for solar radiation concentration. In Parabolic surface, all entering rays parallel to the axis of the parabola are reflected through the focus. This causes concentration of light at the focal point which acts as a receiver (Fig.2). Parabolic trough collectors are widely used for sun radiation concentration at large scale. This type of collectors functioning depends on sun tracking system so that the beam radiation entering parallel to the axis of parabola. The flatter the parabolic reflecting surface; the longer is the focal length. Height of parabolic reflector is one of important parameter used in solar power applications (Figure 1).The design of the parabolic reflector is done with height of the reflector (h), focus distance where receiver would be placed (f), and the available aperture size (a) .The three parameters are related with the equation

$$h = \frac{a^2}{16f}$$

Thermocouple materials convert heat into electrical energy. It works on Seebeck effect which states that if two different materials (semi-conductors or conductors) are kept at different temperatures, electrons would flow continuously in a closed circuit. This results in the creation of electrical potential between junctions.

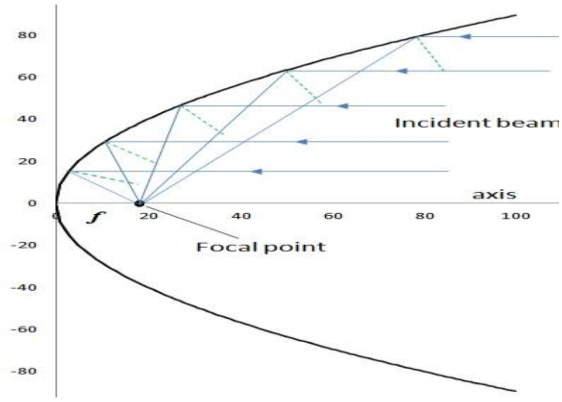


Fig.1 parabola geometry

Generally, thermocouple materials are specified with thermal Power ($\boldsymbol{\alpha}$) which indicates the amount of e.m.f induced per degree centigrade temperature difference between Hot and Cold Junctions. Most commonly used thermocouple materials are copper-constantan, iron-constantan, and copper-iron. Technically performance of thermocouple materials is specified by a special term called as "figure of merit-of-thermoelectricity ($\boldsymbol{Z}$)".

$$\text{Figure of merit of Thermoelectricity } \boldsymbol{Z} = \frac{\boldsymbol{\alpha^2 \sigma}}{\mathbf{K}}$$

Where α: Thermopower V/K
σ: Electrical Conductivity.
K: Thermal Conductivity.

For better performance of Thermocouple materials the value of figure of merit-of-thermoelectricity (Z) must be high. The value of figure of merit can be increased by either increasing the electrical conductivity or by reducing the thermal conductivity of a material but in real life; materials with high electrical conductivity and low thermal conductivity are not easily available. BiTe(Bismuth Telluride) / SbTe(Antimony Telluride) and PbTe(Lead Telluride) / PbSe(Lead Selenium) thin film superlatices can be used as thermocouple materials for getting high figure of merit-of-thermoelectricity. Nowadays, using nanostructured composite material by inversing the behaviour of thermal conductivity and electric conductivity, Z value can be improved. By incorporating nanostructured composites material technology for Thermocouple materials the size of the system can be reduced and efficiency of conversion can also be improved.

II. EXPERIMENTAL SETUP

2.1 Construction:

The system consists of following components:

A. Thermocouple material*:* In this work, we had used a combination of iron, copper, constantan as thermocouple materials. These materials form iron-copper, copper-constant and Iron-Constantan Thermocouple junctions by twisting at their ends. A 48 number of thermocouple junctions were joined to form a series of thermocouples. This series of Thermocouples contain both the hot and cold junctions. Hot junctions are arranged at the surface of perforated Pipe and cold junctions are placed inside the pipe. By using a series of thermocouples, the individual e.m.f generated by each pair of Thermocouple gets added; as a result, a large amount of e.m.f will be obtained at their ends.

The following fig.2 shows a series of Copper-Constantan thermocouples formed by joining at their ends. The junctions are formed by a brazing process. The junctions at the surface of the pipe are called as hot junctions and Junctions at the inside surface of pipe is called as cold junctions. Hot junctions receive the heat by the concentration of solar radiation whereas cold junctions are maintained at low temperatures by using an external cooling medium such as water. In this setup we had used only a single row of series of thermocouples. Similarly copper-iron, Iron-constantan (see fig.2) thermocouple materials were also arranged in the same pattern.

Fig.2. Copper-Constantan Thermocouple

Fig.3. Iron-Constantan thermocouple

B. Parabolic profile surface: In this work, parabolic trough reflector is made with a focal length of 12 inches. The parabolic reflector receives solar radiation from Sun then concentrates at its Focal Point; as a result high-intensity solar radiation is available at the focal point of parabolic trough reflector. This same size and shape of parabolic trough reflector where used along with different Thermocouple materials. The materials used for making parabolic reflector surface are stainless steel, glass and acrylic mirror. Aperture size of parabolic reflector is taken as0.75x0.5 m^2. The fig.4 shows a parabolic reflector surface made of stainless steel materials. A mild steel strip is bent in the form of parabola then stainless steel sheet is attached to the mild steel frame. This stainless steel sheet acts as a reflecting surface which concentrates solar radiation at its Focal Point. Similarly fig. 5 shows parabolic reflector surface with respective glass and acrylic mirror surface.

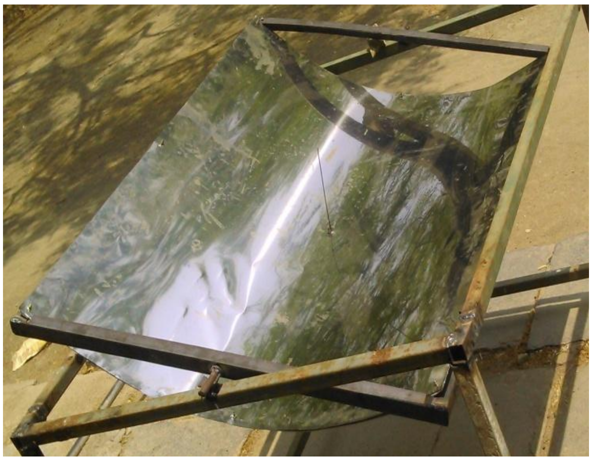


Fig.4. S.S parabolic trough reflector

Fig.5. Glass parabolic trough reflector

C. Specification of Materials Used:
Aperture size: 0.75X0.5 m^2.
Parabolic reflector focal length: 30cm
Parabolic Reflector materials: Glass, S.S, Acrylic mirror.
Thermocouple materials size: 16 SWG
Thermocouple wire leg length: 3cm.
Thermocouple materials: Copper, Iron, Constantan.

2.2 Working:

Direct solar radiation from the Sun falls on parabolic trough reflector surface which concentrates solar radiation at its Focal Point.(see Fig.6) As a result, high-intensity solar radiation is formed at its Focal Point. A series of Thermocouple hot junctions are placed at the focal point of parabolic reflector whereas thermocouple cold junctions are maintained at low temperature by using an external cooling medium. Thus a temperature difference is created between the hot and cold junctions of Thermocouple. This temperature difference induces an e.m.f in the Thermocouple. By connecting thermocouples in series, the e.m.f developed by the individual thermocouples gets added, thus a High Voltage is developed. This induced Voltage and Current is measured with the help of a multimeter.

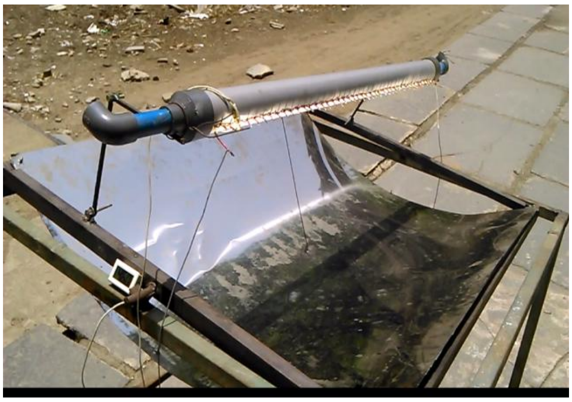


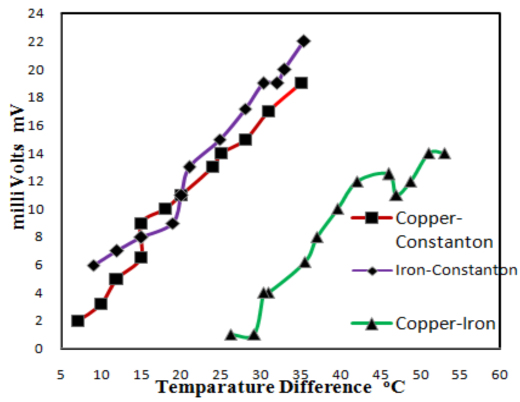
Fig.6. Experimental setup with thermocouple materials and S.S parabolic trough reflector

III. RESULTS AND DISCUSSION

3.1 Results for Thermocouple Materials with S.S Reflecting Surface:

Stainless Steel reflecting surface along with 3 different combinations of thermocouple materials viz. iron, copper, constantan where used in the experimental setup.

Graph.1 represents the experimental data collected for copper-constantan Thermocouple material with stainless steel reflecting surface. During the operation of the device hot junction temperature is maintained constant (as it depends on solar radiation received by the reflector) but cold junction temperature increases from 12^0C to 40^0C due to conduction heat transfer from hot Junction to cold Junction, as a result temperature difference between hard hot and Cold Junction decreasing from 35^0C to 7^0C. Due to the temperature difference between Hot and Cold Junction e.m.f is induced.



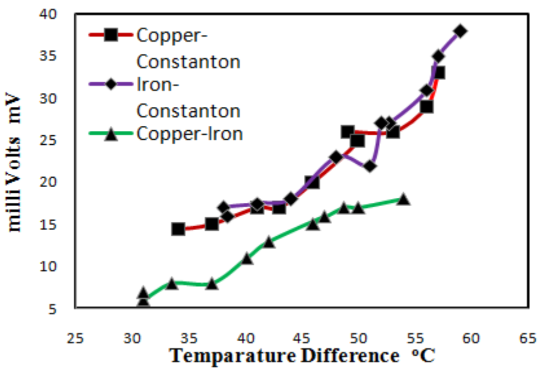
Graph 1: Thermocouple materials with Glass Reflecting Surface

By observing data from graph 1 for Copper-Constantan thermocouple with S.S reflecting surface, we can say that as the temperature difference is reducing from 35 ^{0}C to 7 ^{0}C, e.m.f induced between junctions is also reducing from 19 mV to 2 mV. At a temperature difference of 15 ^{0}C voltage generated per degree centigrade is high with a value of 0.6mV/^{0}C.

For Iron-Constantan thermocouple with S.S reflecting surface, as the temperature reduces from 35^{0}C to 9^{0}C, voltage induced is also reduced from 22mV to 6mV. At a temperature difference of 30^{0}C voltage generated is 19mV but voltage generated per degree centigrade is maximum value of 0.63mV/^{0}C.For Copper-Constantan thermocouple with S.S reflecting surface, as the temperature difference reducing from 35^{0}C to 5^{0}C, voltage induced is also reducing from 14 mV to 1 mV. Maximum voltage generated per degree centigrade is achieved at 24^{0}C with a value of 12.5mV/^{0}C.

3.2 Results for Thermocouple Materials with GLASS Reflecting Surface:

Glass reflecting surface along with 3 different combinations of thermocouple materials viz. iron, copper, constantan where used in the experimental setup.



Graph 2: thermocouple materials with Glass Reflecting Surface

Graph.2 represents the experimental data for copper-constantan Thermocouple with glass reflecting surface. During the experiment hot junction temperature of Thermocouple is maintain constant but cold junction temperature increases continuously from 13^{0}C to 36^{0}C. As a result temperature difference reduces from 57^{0}C to 34^{0}C. For Copper-Constantan thermocouple with Glass reflecting surface, as the temperature difference between Hot and Cold Junction reducing from 57^{0}C to 34^{0}C, the voltage generated is also reducing from 33 mV to 14.5 mV. The maximum voltage generated per degree centigrade is obtained at 57^{0}C temperature difference and its values 0.58 mV/^{0}C.

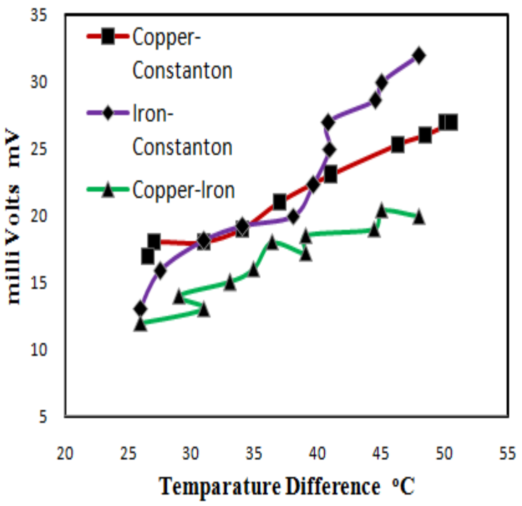
For Iron-Constantan thermocouple with Glass reflecting surface as the temperature difference between Hot and Cold Junction of a thermocouple reducing from 59^{0}C to 38.4^{0}C, voltage generated is also reducing from 38 mV to 16 mV. Among all temperature difference between Hot and Cold Junction, maximum voltage generated per degree centigrade is achieved at 12^{0}C and its value is 0.64 mV / ^{0}C.

For Copper-Iron thermocouple with Glass reflecting surface, as the temperature difference between Hot and Cold Junction of a thermocouple reducing from 54^{0}C to 31^{0}C, voltage generated is also reduced from 18 mV to 7 mV. The maximum voltage generated per degree centigrade is achieved at 48.7^{0}C temperature difference and its value is 0.35 mV /^{0}C.

3.3 Results for Thermocouple Materials with acrylic mirror reflecting Surface:

Acrylic mirror reflecting surface along with 3 different combinations of thermocouple materials viz. iron, copper, constantan where used in the experimental setup.

Graph 3 shows experimental data for copper-constantan Thermocouple with glass reflecting surface. During the experiment hot junction temperature of Thermocouple is maintain constant but cold junction temperature increases continuously from 10.5^{0}C to 35^{0}C; as a result temperature difference reduces from 50^{0}C to 26.5^{0}C. Based graph 3 for Copper-Constantan thermocouple with Acrylic surface, as the temperature difference between Hot and Cold Junction reducing from 50^{0}C to 26.5^{0}C, the voltage generated is also reducing from 27 mV to 17 mV. The maximum voltage generated per degree centigrade is obtained at 37^{0}C temperature difference and its values 0.57 mV/^{0}C.



Graph 3: Thermocouple materials with Acrylic reflecting surface.

For Iron-Constantan thermocouple with acrylic reflecting surface, as the temperature difference between Hot and Cold Junction of a thermocouple reducing from 48^0C to 26^0C, voltage generated is also reducing from 32 mV to 13 mV. Among all temperature difference between Hot and Cold Junction, maximum voltage generated per degree centigrade is achieved at 16^0C and its value is 0.67 mV / ^{0}C.

For Copper-Iron thermocouple with Acrylic reflecting surface, as the temperature difference between Hot and Cold Junction of a thermocouple reducing from 48^0C to 26^0C, voltage generated is also reduced from 20 mV to 12 mV. The maximum voltage generated per degree centigrade is achieved at 36.4^0C temperature difference and its value is 0.49 mV /^{0}C.

3.4 Performance calculations:

Among the three thermocouple materials with different parabolic trough reflectors, optimum voltage and current is produced for an Iron-Constantan thermocouple (48 numbers of junctions in series) with glass mirror reflective surface.

Voltage = 38mV (for 48 number of junctions in series)

Current = 0.01A

Direct normal incidence of solar energy at a location =1.03 kW/m^2

Aperture effective area =0.75x0.5 = 0.375m^2

Direct normal radiation received by parabolic trough reflector E_i=1.03x0.375 kW = 386.25 W

Electrical energy available at load E_o = VxI

= 0.038x0.01

= 0.00038W

Efficiency of energy conversion

$$\eta = \frac{electical\ \ enegy\ \ at\ load\ \boldsymbol{E_o}}{solar\ \ energy\ \ received\ \ \boldsymbol{E_i}} = \frac{\boldsymbol{E_o}}{\boldsymbol{E_i}} = \frac{0.00038}{386.15} x10$$

= 0.01%

The efficiency of energy conversion achieved is 0.01% for a 48 number of thermocouples junctions in series with temperature difference of 59 ^{0}C.

IV. FACTORS TO IMPROVE THE PERFORMANCE

4.1 Increasing Hot Junction Temperature:

A. Increasing the size of aperture: The amount of direct solar radiation received by parabolic trough reflector can be varied by size of aperture. Varying the size of aperture for the same curvature of the parabola doesn't affect the focal length. As the size of aperture increases, the amount of solar radiation received by the parabolic reflector increases. As a result, more intensity of high intensity of solar radiation is concentrated at the focal point. This high intensity of solar radiation at Focal Point increases the heart junction temperature, which increases temperature difference between thermocouples. Thus more EMF is induced.

B. Increasing curvature of parabola: The focal length of the parabola can be varied by varying its curvature. For same aperture size as the curvature of parabola increases the focal length reduces and vice versa (sees fig.1). By increasing the curvature of the parabola focal length reduces due to this parabolic reflector concentrates solar radiation nearer to its vertex. Due to this solar radiation concentration takes place within the body of a parabolic reflector. This arrangement reduces convection and radiation losses. This also complicates design of supporting structure for Thermocouple setup. Increasing the curvature of parabola also complicate tracking system needed for controlling the parabolic trough reflector with the position of the Sun.

C. Materials for reflective surface*:* By using a highly reflective surface with high surface finish more about of amount of solar radiation is concentrated at its Focal Point which increases the temperature of hot Junction. The most common commonly used reflecting surface materials are glass, stainless steel.

D. Sun tracking system*:* As the sun position change from east to west the amount of direct solar radiation received by the parabolic trough reflector also vary. By providing tracking system to parabolic reflectors the system can be controlled to receive maximum amount of direct solar radiation. Generally solar tracking assisted systems can receive more direct solar radiation as it can be positioned normal to the suns solar radiation.

4.2 thermocouple materials:

Efficient Conversion of heat into electrical energy by a Thermocouple material depends on reducing the thermal conductivity of a material while improving the material thermo power and electrical conductivity. Naturally available materials don't have an inverse behaviour of thermal conductivity and electrical conductivity. By using BiTe(Bismuth Telluride)/SbTe(Antimony Telluride) / and PbTe(Lead Telluride)/PbSe(Lead Selenium) thin film superlattices can be used for producing thermocouple materials for getting high conversion efficiency. Nowadays by using nanostructured composites material with the inverse behaviour of thermal conductivity and electric conductivity is possible. By incorporating nanostructured composites material technology for Thermocouple materials the size of the system can produce and efficiency of conversion can also be improved.

4.3 reducing cold junction temperature:

By providing proper insulation between upper and lower surface of perforated pipe conduction heat transfer can be reduced as a result the small quantity of heat need to be removed from the cold junction. Cold junction temperature can be reduced by providing external cooling medium such as water etc.

V. CONCLUSION

In this work, the solar energy was converted into electrical energy by using parabolic collector and thermocouple materials. A number of Thermocouple materials with parabolic collector combinations where used to perform experiments. Three thermocouple materials (copper, iron, and constantan) were used for each of three reflecting surfaces (stainless steel, glass, acrylic) to perform experiments.

The resulting data summarised as follows:

- For iron - constantan Thermocouple materials with stainless steel reflecting surface, a voltage of 32mV is produced for 35.4^0C temperature difference.
- Iron-constantan Thermocouple materials with glass reflecting surface, a voltage of 38mV is produced for 59^0C temperature difference.
- Iron-constant Thermocouple material with acrylic mirror surface 32mV is produced 48^0C temperature difference.
- A highest efficiency of energy conversion o.o1% where achieved at 38 mV voltage, 0.01A current and 59^0C temperature difference with iron constantan Thermocouple and glass reflecting surface.
- For all thermocouple materials with a respective reflecting surface, as the temperature difference between Hot and Cold junction increases voltage induced is also increasing.
- Among the thermocouple materials with respective reflecting surfaces, highest 0.64 mV/C (highest voltage induced per degree centigrade temperature difference) is achieved for an iron-Constantan Thermocouple with glass reflecting surface.

The experimental setup is made with an ordinary thermocouple materials and reflecting surfaces which has a conversion efficiency of 0.01%. However, by using advanced thermocouple materials and better reflecting surface coating a further improvement in efficiency can be achieved

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