Fabrication of Solar Thermoelectric Refrigeration System

K. Ajith Kumar[1], M. D. Umar[1], G. Praveen[1], R. Vishnu Vardhan[1], G. Praveen Kumar Yadav[1]
[1] Department of Mechanical Engineering, G Pulla Reddy Engineering College, Kurnool, Andhra Pradesh, India;
Corresponding Author: gandikotapraveenkumar@gmail.com

Abstract— The conventional refrigeration system uses refrigerant that harms the environment and depletes the ozone layer. The commonly used refrigerants are CFC's and HFC's. Though HFC's has less effect over the ozone layer as compared to the CFC's but it still plays a role in depletion of ozone layer. A huge time would be required to make the complete system eco-friendly Moreover the other factors like extra power consumption, maintenance, service etc. lead to find an alternative for existing refrigerating system. Thermoelectric Solar refrigeration system has a solution to these advantages. In our project main use of solar power which is nature's free gift is used to drive the thermoelectric module. The solar energy is converted into electrical energy through solar panel which is then given to the thermoelectric module. In case of insufficient solar energy, electrical energy can be used to charge the battery. As the electric current is given to the thermoelectric module due to Peltier effect temperature difference occurs. The blowers extract the heat from the cold side and the cold air is circulated in the conditioned space by changing the polarity hot air can be circulated in the conditioned space. The main purpose of this project is to provide refrigeration to the remote areas where power supply is not possible.

Keywords— Peltier effect, Refrigeration, Solar energy, Thermoelectric module, Heat sink.

1 INTRODUCTION

Refrigeration is a process in which work is done to remove heat from one location to another. If you were to place a hot cup of coffee on a table and leave it for a while, the heat in the coffee would be transferred to the materials in contact with the coffee, i.e. the cup, the table and the surrounding air. As the heat is transferred, the coffee in time cools. Using the same principle, refrigeration works by removing heat from a product and transferring that heat to the outside air. Refrigeration is used to cool products. The refrigeration system (R) transfers heat from a cooler low-energy reservoir to a warmer high-energy reservoir.

Refrigeration has many applications including but not limited to household refrigerators, cryogenics, air conditioning, and heat pumps. Since the turn of the century, there has been steady growth of application of refrigeration in preservation of perishable food products, agriculture and fishery. The purpose of refrigeration for food is to retard deterioration by micro-organisms, chemical and physical processes. By cooling at temperatures just above freezing it is possible to achieve a limited extension of storage time which is often sufficient for safe distribution and marketing. By freezing to temperature as low as -30^{O}C, deterioration can be slowed down further and this increases the storage time.

1.1 Thermoelectric Effect

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an

applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side.

The term "thermoelectric effect" encompasses three separately identified effects: the **Seebeck** effect, **Peltier** effect, and **Thomson** effect.

1.2 Seebeck effect

The Seebeck effect is the conversion of heat directly into electricity at the junction of dissimilar electrical conductors. It is named for the Baltic German physicist Thomas Johann Seebeck.

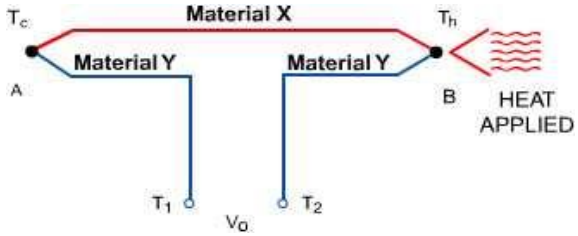


Fig. 1 Seebeck effect

As shown in Figure 1, the conductors are two dissimilar metals denoted as material A and material B. The junction temperature at A is used as a reference and is maintained at a relatively cool temperature (T_C). The junction 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 continuously in this closed circuit. This voltage is known as the Seebeck EMF, can be expressed as

$E_{out} = \alpha (T_H - T_C)$

Where:

- $\alpha = dE / dT = \alpha A - \alpha B$
- α is the differential Seebeck coefficient or (thermo electric power coefficient) between the two materials, A and B, positive when the direction of electric current is same as the direction of thermal current, unit is V/K.
- Eout is the output voltage in volts.
- T_H and T_C are the hot and cold junction temperatures, respectively, in Kelvin.

1.3. Peltier effect

Peltier found there was an opposite phenomenon to the Seebeck Effect, whereby thermal energy could be absorbed at one dissimilar metal junction and discharged at the other junction when an electric current flowed within the closed circuit.

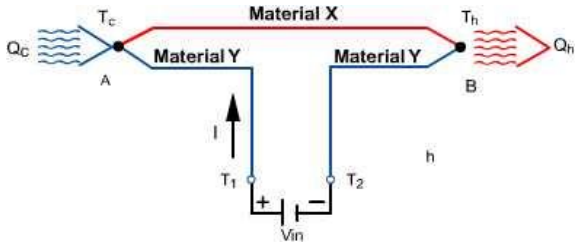


Figure.2 Peltier effect

In Figure 2, the circuit is modified to obtain a different configuration that illustrates the Peltier Effect, a phenomenon opposite 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. As a result of the current flow, a slight cooling effect (Q_C) will occur at thermocouple junction A (where heat is absorbed), and a heating effect (Q_H) will occur at junction B (where heat is expelled). Note that this effect may be reversed whereby a change in the direction of electric current flow will reverse the direction of heat flow.

Joule heating, having a magnitude of I^2 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 opposition to the Peltier Effect and causes a net reduction of the available cooling. The Peltier effect can be expressed mathematically as

Q_C or $Q_H = \beta \times I = (\alpha T) \times I$

Where:

- β is the differential Peltier coefficient between the two materials A and B in volts.
- I is the electric current flow in amperes.
- Q_C and Q_H are the rates of cooling and heating, respectively, in watts.

1.4 Thomson effect

As per the Thomson effect, when an electric current is passed through a conductor having a temperature gradient over its length, heat will be either absorbed by or expelled from the conductor. Whether heat is absorbed or expelled depends on the direction of both the electric current and temperature gradient. This phenomenon, known as the Thomson Effect, is of interest in respect to the principles involved but plays a negligible role in the operation of practical thermoelectric modules. For this reason, it is ignored.

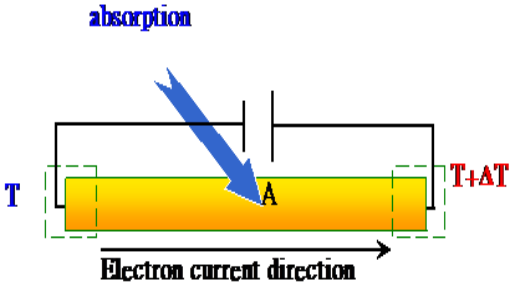


Figure.3 Thomson effect

Two unique semi-conductors, one n-type & one p- type are used because that needs to have different electron densities. The semi-conductors are placed thermally in parallel to each other and electrically in series and that joined with a thermally conducting plate on each side. When a voltage is applied to the free ends of the two semi-conductors there is a flow of DC current across the junction on semi-conductor causing a temperature difference. The side with the cooling plate absorbs heat which is then move to the other side of the device where the heat sink is. TECs are typically connector side by side and sandwich between two ceramic plates the cooling ability of the total unit is then proportional to the number of TECs in it.

2 COMPONENTS OF SOLAR THERMOELECTRIC REFRIGERATION SYSTEM:

2.1 Thermoelectric Module:

A thermoelectric module consists of arrangements of number of P-type and N-type semiconductor which are heavenly doped with electron carrier and sandwiched between two ceramic substrates. These elements are arranged in a way that is electrically connected in series but thermally connected in parallel. The most often used in today's TE coolers is an alloy of Bismuth Telluride (Bi2Te3). • In addition to Bismuth Telluride (Bi2Te3), there are other thermoelectric materials including Lead Telluride (Pb-Te), Silicon Germanium (Si-Ge) and Bismuth-Antimony (Bi-Sb) alloys that may be used in specific situations. Thermoelectric Materials should posses:-

1. Large Seebeck Coefficients (to minimize Joule heating). 2. High Electrical Conductivity. 3. Low Thermal Conductivity (to retain heat at the junctions)

The most commonly used semiconductor for electronics cooling applications is Bi2Te3 because of its relatively high figure of merit. However, the performance of this material is still relatively low and

alternate materials are being investigated with possibly better performance.

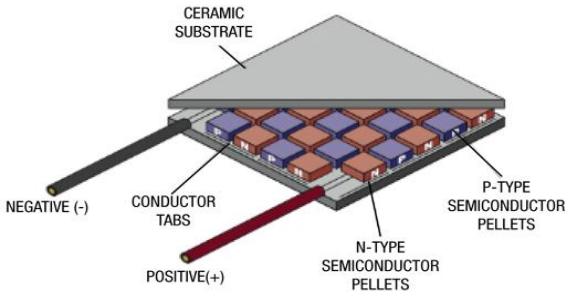


Fig.4 Thermoelectric Module

2.2 Solar Panel:

Solar panel consists of solar photovoltaic cells which converts solar energy into electrical energy. Solar photovoltaic module is the array of number of electrically connected solar cell mounted on a frame. Modules are designed to supply the electricity at certain voltage. The efficiency of the module and current supply by it is totally depend upon the amount of solar radiation fall on the surface of the PV module.

Fig.5 Solar Panel

2.3 Battery:

Battery used in this project stores the energy received from the solar panels. Peltier device is powered by 12v battery. An electric battery is a device consisting of two or more electrochemical cells that convert stored chemical energy into electrical energy. each cell has a positive terminal, or cathode, and a negative terminal, or anode. the terminal marked positive is at a higher electrical potential energy than is the terminal marked negative. the terminal marked negative is the source of electrons that when connected to an external circuit will flow and deliver energy to an external device.

Fig.6 Battery

2.4 Heat Sink:

A heat sink is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device into a coolant fluid in motion. Then-transferred heat leaves the device with the fluid in motion, therefore allowing the regulation of the device temperature at physically feasible levels. A perfect heat sink would be capable of absorbing an unlimited quantity of heat without exhibiting any increase in temperature. Heat sink cools a device by dissipating the heat into

surrounding medium, it consists of fin blade due to which the surface area for cooling increase and hence the cooling effect obtained.

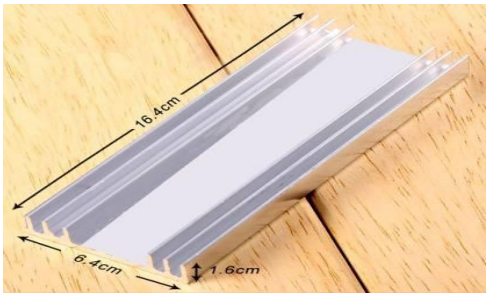


Fig.7 Heat Sink

2.5 Heat Sink Fan:

Sometimes the heat sink itself becomes hot during the heat transfer to overcome this problem a device called heat sink fan is used for the removal of induced heat in the fins of the heat sink. So these fans are attached over the fins of the heat sink and it cools down the heat produced in the heat sink.

Fig.8 Heat Sink Fan

2.6 Temperature Sensor:

A temperature sensor is a device, usually an RTD (resistance temperature detector) or a thermocouple, that collects the data about temperature from a particular source and converts the data into understandable form for a device or an observer. The temperature indicator is device that is used to know about the temperature inside the chamber of refrigerator. It has a probe which is inserted inside the chamber of refrigerator and the probe senses the temperature inside and gives the temperature data to the output display.

Fig.9 Temperature Sensor

2.7 Chamber:

The chamber to be cooled is made up of thermocol, as it is easily available, economical and also having good property to been used as insulation purpose as its do not allow the inner temperature to be much affected by the ambient. As we know the ice vendors take advantage of thermocol for its economic value and good insulation property as it does not allow the inner temperature of cooling medium to go down. Hence it is also an economic source of insulation. So the external structure of the whole refrigerator is made of thermocol.

Fig.10 Chamber

2.8 Fabrication of Model:

Firstly a box of Thermocol is made of given dimensions and the thermocol box is attached to the wooden platform. The thermocol box is mounted with a Peltier device at the side and bottom with the help of thermal paste. At the side of the thermocol box a small rectangular box is made in which hot side of the Peltier is faced.

Fig.11 Solar Thermoelectric Refrigeration System

The system consists of a Peltier module attached to an insulated thermocol enclosure. The Peltier module is attached to the heat sink to dissipate the heat generated during cooling process , a switching circuit is also used to change the polarity of the current being given to the Peltier module. A 12V cooling fan is fitted in the enclosure to circulate the air from inside the enclosure to its surroundings. LM35 temperature sensor is placed inside the enclosure to sense the temperature. The temperature sensor is connected to an LCD after interfacing to display the temperature in the enclosure. The terminals of the Peltier devices, and battery should be connected properly. The refrigeration is powered by electrical energy which is collected from solar or from power supply. The peltier is sandwiched between heat sinks, which produces thermal effect or cooling effect when power passed. This cools the air passing inside the chamber and blow out the cool air. The cooling fan mounted on the heat sink throws out the excess of hot air which is generated by the hot side of the peltier.

3 OBSERVATIONS AND RESULTS

3.1 TEC Specification

In this experiment we use TEC1-127-06L a thermoelectric module, which specification are as follow.

Table : Model Number for TER			
Module: Model TEC1-127-06L			
Q_{max}	60 Watts	Dimensions	
I_{max}	6 Amp	Width	40 mm
V_{max}	15.4 V	Length	40 mm
T_{max}	90 °C	Thickness	3.5 mm
Number of Thermocouple	127		

3.2 Design & measurement of temperature

Every specific application where a thermoelectric cooler module or refrigerator is required is characterized by a set of operation parameters, which dictate the necessity and accurate selection of the optional thermoelectric cooler type among a wide range of single and multi-stage thermoelectric cooler modules.

A.Thermoelectric Cooler Module

The thermoelectric cooler module material chosen is Bismuth telluride. The properties of a 127 couple, 6A Bismuth Telluride module TEC1-127-06L are:

Seebeck coefficient (S) = 0.01229 V/k

Module thermal conductance (K) = 0.1815 W/k

Module resistance (R) = 4Ω

B. Thermal Resistance Network

Thermal resistance network is conducted here for analysis. Since TEC generates Joule heat, it makes heat rejection, which is called Q_H, from TEC hot side larger than the heat absorption, which is called Q_L, into TEC cold side. According to literatures, the general forms of heat absorption and heat rejection are presented as bellow. Heat transferred into the cold side when neglected the temperature drop through the TEC is given by,

$$Q_L = [SITc - ½ I^2R - k (T_h - T_c)]$$

(-) sign for heat rejection.

While the heat transferred out of the hot side into the heat sink is given by,

$$Q_H = [SITh + ½ I^2R - k (T_h - T_c)]$$

Seebeck coefficient (S) and electrical resistance (R) in Ohms are dependent both on the materials used within the TEC, but also on the geometry of the device, given by the number and dimensions of the individual N and P-type semiconductor elements.

C. Temperature difference

SNO.	TIME DURATION [IN MIN]	TEMPERATURE [°C]
1	0	38.3
2	0:28	35.1
3	1:01	31
4	1:32	28.4

5	2:03	26.9
6	2:34	26.1
7	3:06	25.6
8	3:36	25.2
9	3:57	25.1
10	4:49	24.8
11	5:28	24.6
12	6:12	24.5
13	6:40	24.4

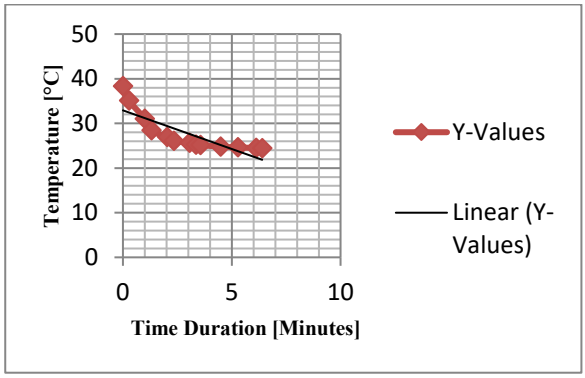
Table 1 Observation table

After measuring the temperature by using temperature sensor, final temperature at the surface of module and the heat sink are as follow.

Temperature at hot side T_h = 38.3˚ C
Temperature at cold side T_c = 24.4˚ C
So, Temperature difference can be considered as

$\Delta T = (T_h - T_c) = (38.3\text{-}24.4) = 13.9^{\circ}C$

3.3 Graph Between Temperature Vs Time :



.

Fig.12 Graph between Temperature Vs Time

3.4 COP of Single stage thermoelectric module

A non-dimensionless parameter called the Coefficient of Performance is therefore used to measure the performance of a cooling machine. The coefficient of performance (COP) of a thermoelectric module which is the thermal efficiency must be considered for a TE system. COP is the ratio of the thermal output power and the electrical input power of the TEC. COP can be calculated by dividing the amount of heat absorbed at the cold side to the input power. COP = QL/Energy supplied (W)
Heat absorption is calculated as below.
$Q_L = [SITc - ½ I^2R - k (T_h - T_c)] = 72.723594$ J
From the first law of thermodynamics, the Energy supplied is:
Energy supplied, $W = Q_H - Q_L$
$= SI (T_h - T_c) + I^2R = 145.024$ J
The Coefficient of Performance (COP) is obtained by the following empirical equation.

COP = Q_L/Energy supplied

$$= \frac{[SITc - ½ I^2R - k (Th - Tc)]}{SI (Th - Tc) + I^2R}$$

$$= \frac{72.723594}{145.024}$$

COP = 0.501

4 CONCLUSIONS

Solar thermoelectric refrigeration system is fabricated and tested for cooling. The peltier(thermoelectric) module obtained a lower temperature of 24.4 °C from 38.3°C with a temperature difference of 13.9°C. This temperature difference is observed in a span of 6 min 40 seconds. The coefficient of performance (COP) of this module is calculated and found to be 0.501. Though the COP of thermoelectric refrigeration system is lesser than the conventional one, efforts can be made to develop thermoelectric domestic coolers to exploit the advantages associated with solid state energy conversion technology.

REFERENCES

[1]H. Julian Goldsmid, Bismuth Telluride and Its Alloys as Materials for Thermoelectric Generation, Materials 2014, 7, 2577-2592.
[2]S. Stackhouse, L. Stixrude, Theoretical Methods for Calculating the Lattice Thermal Conductivity of Minerals, Mineralogy & Geochemistry Vol. 71 pp. 253-269, 2010.
[3]Melcor homepage http://www.melcor.com (assessed on October, 2015)
[4]S. Riffat, S.A. Omer, Xiaoli Ma, A novel thermoelectric refrigeration system employing heat pipes and a phase change, Renewable Energy 23 (2001) 313–323
[5]R. Chein, Y. Chen, "Performances of thermoelectric cooler integrated with microchannel heat sinks", International Journal of Refrigeration 28 (2005) 828–839
[6]S. Riffat, X. ma, Improving the coefficient of performance of thermoelectric cooling systems, international journal of energy research Int. J. Energy Res. 2004; 28:753–768
[7]C. Hermes, J. Barbosa, "Thermodynamic comparison of Peltier, Stirling, and vapor compression portable coolers", Applied Energy 91 (2012) 51–58
[8]J. Vian, D. Astrain, "Development of a heat exchanger for the cold side of a thermoelectric module", Applied Thermal Engineering 28 (2008) 1514–1521
[9]Kaseb S., El-hairy G, *Electronics Cooling*, Mechanical Power Engineering Department, Faculty of Engineering, Cairo University, Egypt
[10] Thermoelectric cooling FAQ, Tellurex Corporation
[11] Marc H., *Thermoelectric Modules: Principles and Research*, InterPACK july 6-8, 2011, Portland
[12] Kaseb S., El-hairy G, *Electronics Cooling*, Mechanical Power Engineering Department, Faculty of Engineering, Cairo University, Egypt
[13] Enescu D, Virjoghe EO, *A review on thermoelectric cooling parameters and performance*, Renewable and Sustainable Energy Reviews , 2014, 38:903–916
[14] Goldsmith, H.J. , *Introduction to thermoelectricity*, Springer-Verlag Berlin Heidelberg 2010