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Thermoelectric Based Solar Powered Refrigeration System

Abhishek Sharma[1], Alka Bani Agrawal[2] and Nitin Shrivastava[3]
[1]Department of Mechanical Engineering,
Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, (Madhya Pradesh) India.
[2]Professor, Department of Mechanical Engineering,
Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, (Madhya Pradesh) India.
[3]Associate Professor, Department of Mechanical Engineering,
Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, (Madhya Pradesh) India.

(Corresponding author: Abhishek Sharma)
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ABSTRACT: This paper utilizes the thermoelectric (Peltier) module for refrigeration powered by the solar panel is going to be one of the most cost effective, clean and environment friendly system for refrigeration. Thermoelectric refrigeration uses a principle called the "PELTIER" effect to pump heat electronically. In our proposed refrigeration system we does not need any kind of refrigerant, mechanical device like compressor, prime mover, etc. for its operation. We are dealing with Peltier module and solar panel and some accessories. Thermoelectric modules are constructed from a series of tiny metal cubes of dissimilar exotic metals which are physically bonded together and connected electrically. When electrical current passes through the cube junctions, heat is transferred from one metal to the other. Using MATLAB we are modifying design and working on a model and compare the COP with the existing model and analyze that the COP of these devices get improved. The main purpose of this project is to provide refrigeration in the remote areas where power supply is not possible.

Keywords: Peltier, Refrigeration, Renewable Energy, Seebeck, Thermoelectric, Thomson Effect

I. INTRODUCTION

Renewable & alternative non-conventional green energy technologies used for heat-pumping applications have shown real merits and received renewed interest in recent years especially in small-scale portable heating applications. Solar-driven thermoelectric heat pumping is one of these innovative technologies [1]. Solar energy is theuniversal source of energy as sunshine's throughout at the lowest cost,. This energy can be converted into useful electrical energy using photovoltaic technique. Thermoelectric heating (or cooling) technology has received renewed interest recently due to its distinct features compared to conventional technologies, such as vapour-compression and electric heating (or cooling) systems. Thermoelectric (TE) modules are solid-state heat pumps (or refrigerators in case of cooling) that utilize the Peltier effect between the junctions of two semiconductors. The TE modules require a DC power supply so that the current flows through the TE module in order to cause heat to be transferred from one side of the TE module to another, thus creating a hot and cold side [2, 3]. The main objective of the model is to makeauseful refrigeration machine for the people who live in the remote areas of the country where load-shading is a major problem.From last century till now refrigeration has been one of the most important factors of our daily life. The currenttendency of the world is to look at renewable energy resources as a source of energy. This is done for the following two reasons; firstly, the lower quality of life due to air pollution; and, secondly, due to the pressure of the ever increasing world population put on our natural energy resources.

From the avobe two facts, it comes to the realization that the natural energy resources available will not last indefinitely. The basic idea is an implementation of a photovoltaic driven refrigerating system powered from a direct current source or solar panel (when needed) with a battery bank. In 1821, the first important discovery relating to thermoelectricity occurred by German scientist Thomas Seebeck who found that an electric current would flow continuously in a closed circuit made up of two dissimilar metals, provided that the junctions of the metals were maintained at two different temperatures. Without actually comprehending the scientific basis for the discovery, See beck, falsely assumed that flowing heat produced the same effect as flowing electric current. Later, in 1834, while investigating the See beck Effect, a French watchmaker and part-time physicist, Jean Peltier found that there was an opposite phenomenon whereby thermal energy could be absorbed at one dissimilar metal junction and discharged at the other junction when an electric current flows within the closed circuit. Afterwards, William Thomson described a relationship between See beck and Peltier Effect without any practical application. After studying some of the earlier thermoelectric work, Russian scientists in 1930s, inspired the development of practical thermoelectric modules based on modern semiconductor technology by replacing dissimilar metals with doped semiconductor material used in early experiments.

The Seebeck, Peltier and Thomson effects, together with several other phenomena, form the basis of functional thermoelectric modules. Thermoelectric Refrigeration aims at providing a cooling effect by using thermoelectric effects rather than the more prevalent conventional methods like those using the ‘vapour compression cycle’ or the ‘gas compression cycle’. The Seebeck coefficient is the ratio between the electric field and the temperature gradient. The Seebeckcoefficient can be thought of as a measure of the coupling between the thermal and electrical currents in a material. The Peltier coefficient of the junction is a property depending on both materials and is the ratio of the power evolved at the junction to the current flowing through it. Thomson coefficient is the ratio of the Power evolved per unit volume in the sample to the applied current and temperature gradient.

II. THERMOELECTRIC DEVICES

A Peltier element is a thermoelectric cooler, or TEC, which is simply a small heat pump. In 1821 J.T. Seebeck discovered that two dissimilar metals connected at two different junctions create a micro voltage between them if held at two different temperatures [3]. If two wires are connected, for example iron and copper, and the other ends applied to the terminals of a galvanometer a voltage can be recorded if the junction between the wires is heated. The wires are called a thermocouple [4] J. Peltier realized, in 1834, that the inverse effect is possible as well. If a voltage is applied to a thermocouple a temperature difference will be initiated between the junctions. This is known as the Peltier effect [3]. A heating or cooling effect of the junction is created depending on the direction of the current. In 1855 the dependency between the temperature change and the current application was proven by W. Thomson (or Lord Kelvin) who, by applying thermodynamics, established the relationship between the coefficients that described the Peltier and Seebeck effects, which is now known as the Thomson effect [4]. This effect described reversible heating or cooling when there is a temperature gradient along with an electric current. What happens is the electrons carrying out the current possess different energy depending on the material. When the current reaches the junction it is transferred from one material to another and the energy is altered, causing the junction to heat up or cool down. Likewise, if the junction is heated the electrons can pass from the material with lower energy to that with higher, giving rise to an electromagnetic force.

There are different thermoelectric material are used like skutterudite, oxides, antimonide, PbTe based etc. Each material has different mechanical properties.

Table 1: Mechanical Properties Of Thermoelectric Material.

Material	Young's modulus	Fracture strength	Hardness
Skutterudite	133-140	35- 85	-
Oxides	85-210	-	2.5- 11.75
Antimonide	74	65	1.56
PbTe Based	54-55	28	0.98- 1.27

In the above table mention the values of mechanical properties of each material, which is helpful during the selection of thermoelectric module. Thermoelectric material has following mechanical properties.

The Zt value is calculated using the formula:

$$Z = S^2 \Sigma \times T/K \quad (1)$$

Where:

T - absolute temperature

S - Seebeck coefficient

Σ - electrical conductivity

K - thermal conductivity

A. Peltier Effect

If direct current is passed through two dissimilar metals then a potential difference will be developed across the two dissimilar metals. There will be cooling at one junction and heating at another junction. Peltier says that charge is directly proportional to current which means when voltage is applied to the Peltier device, then the current will be developed and due to the current, charge will be generated and due to charge a potential difference will be developed between two dissimilar metals[5].

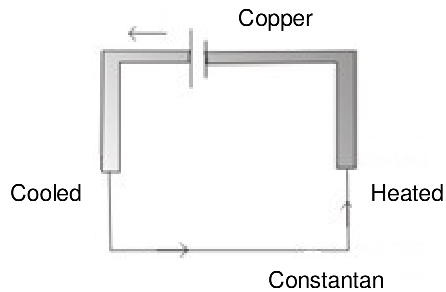

Fig. 1. Peltier Effect.

$$q \; \alpha \; I \quad (2)$$

$$q = \pi ab \; I \quad (3)$$

Where

q= Peltier heating and cooling rate.

πab= Peltier coefficient.

Basic features of Peltier Module are:

- Conventional system can use or generate harmful gasses like ChloroFluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs).The Peltier module can't use or generate these harmful gasses.
- The conventional refrigeration system can generate some noise during operation. The Peltier module can't generate any noise during operation. It is quite in operation.
- Peltier module can operate on DC power source.
- By using the proper closed loop circuit, the Peltier module can control precise temperature.
- Long life, with mean time between failures (MTBF) exceeding 100,000 hours.
- Controllable via changing the input voltage/current.

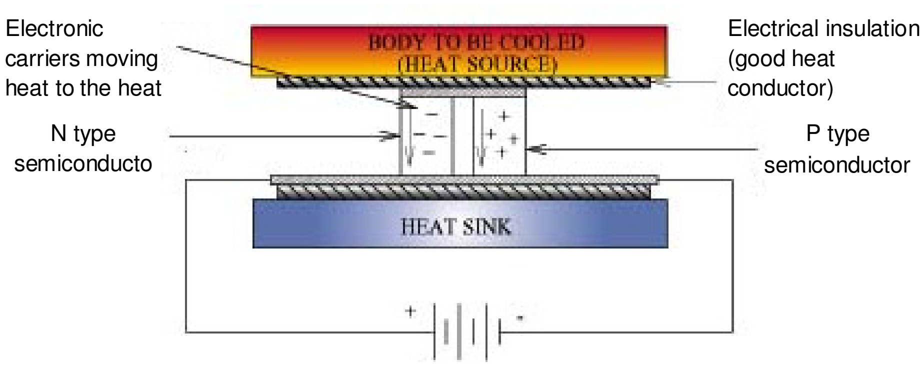

Fig. 2. Cross section of Peltier element view.

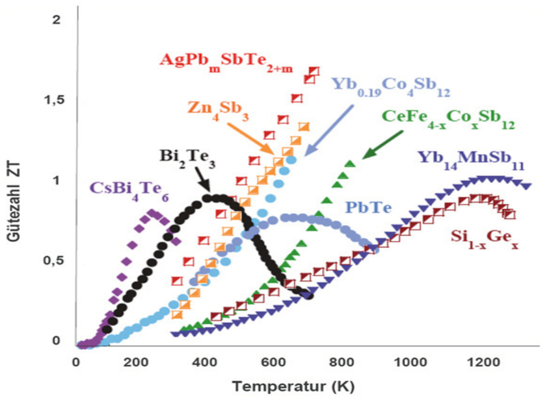

Fig. 3. Chart for diversity of Peltier element material.

A choice of different Peltier elements in different categories is High Performance, High Temperature, Micro, Multi-Stage, Special Shapes, series-parallel connection and Standard. From these it is possible to immediately eliminate High Temperature, Multi-Stage, Micro, Series-Parallel connection and Special Shapes, due to over design to the requirements and costs. Therefore, selection is made between High Performance and Standard.

B. Thomson Effect

In different materials, the Seebeck coefficient is not constant in temperature, so a spatial gradient in temperature can result in a gradient in the Seebeck coefficient. If a current is driven through this gradient then a continuous version of the Peltier effect will occur. This Thomson effect was predicted and subsequently observed by Lord Kelvin in 1851. It describes the heating or cooling of a current-carrying conductor with a temperature gradient[5,6]. If a current density J is passed through a homogeneous conductor, the Thomson effect predicts a heat production rate q per unit volume of:

$$\dot{q} = kJ.\nabla T \quad (4)$$

C. Seebeck Effect

The Seebeck effect is the conversion of heat directly into electricity at the junction of different types of wire. It is named for the Baltic German physicist Thomas Johann Seebeck, who in 1821 discovered that a compass needle would be deflected by a closed loop formed by two different metals joined in two places, with a temperature difference between the joints. This was because the electron energy levels in each metal shifted differently and a voltage difference between the junctions created an electrical current and therefore a magnetic field around the wires. Seebeck did not recognize there was an electric current involved, so he called the phenomenon "thermomagnetic effect." [5]. Danish physicist Hans Christian Ørsted rectified the oversight and coined the term "thermoelectricity". TheSeebeck effect is a classic example of an electromotive force (emf) and leads to measurable currents or voltages in the same way as any other emf. Electromotive forcemodifyOhm's law by generating currents even in the absence of voltage differences (or vice versa); the local current density is given by:

$$J = \sigma(-\nabla V + \text{Eemf}) \quad (5)$$

Where V is the local voltage and σ is the local conductivity. In general, the Seebeck effect is described locally by the creation of an electromotive field:

$$E = -S\nabla\mathrm{T} \quad (6)$$

Where S is the Seebeck coefficient (also known as thermopower), a property of the local material, and ∇T is the gradient in temperature T.

The Seebeck coefficient (also known as thermopower, thermoelectric power, and thermoelectric sensitivity) of a material is a measure of the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material, as induced by the Seebeck effect. The SI unit of the Seebeck coefficient is volts per kelvin (V/K), although it is more often given in microvolts per kelvin (μV/K). The use of materials with a high Seebeck coefficient is one of many important factors for the efficient behaviour of thermoelectric generators and thermoelectric coolers. More information about high-performance thermoelectric materials can be found in the Thermoelectric materials article. In thermocouples the Seebeck effect is used to measure temperatures, and for accuracy it is desirable to use materials with a Seebeck coefficient that is stable over time [7].

$$S = -\frac{\Delta \mathrm{V}}{\Delta \mathrm{T}} \quad (7)$$

Where ΔV is the thermoelectric voltage seen at the terminals.TheSeebeck coefficient is defined in terms of the portion of electric current driven by temperature gradients, as in the vector differential equation:

$$J = -\sigma\nabla V - \sigma S\nabla T \quad (8)$$

D. Solar Photovoltaic

Photovoltaic (PV) is the technical term for solar electric. Photo means "light" and voltaic means "electric". PV cells are usually made of silicon, an element thatnaturally releases electrons when exposed to light. The amount of electrons released from silicon cells depends upon intensity of light incident on it. The silicon cell is covered with a grid of metal that directs the electrons to flow in a path to create an electric current. This current is guided into a wire that is connected to a battery or DC appliance [8,9].

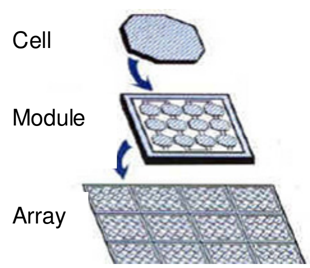

Fig. 4. Solar Photovoltaic Array.

Typically, one cell produces about 1.5 watts of power. Individual cells are connected together to form a solar panel or module, capable of producing 3 to 110 Watts power. Panels can be connected together in series and parallel to make a solar array(see Figure 4), which can produce any amount of Wattage as space will allow. Modules are usually designed to supply electricity at 12 Volts. PV modules are rated by their peak Watt output at solar noon on a clear day. Some applications for PV systems are lighting for commercial buildings, outdoor (street) lighting, rural and village lighting, etc.

Solar electric power systems can offer independence from the utility grid and offer protection during extended power failures. Solar PV systems are found to be economical, especially in the hilly and far flung areas where conventional grid power supply will be expensive to reach [10].

PV tracking systemis an alternative to the fixed, stationary PV panels. It is mounted and provided with tracking mechanisms to follow the sun as it moves through the sky. These tracking systems run entirely on their own power and can increase output by 40%.Back-up systemsare necessary for PV systems only generate electricity when the sun is shining. The two most common methods of backing up solar electric systems are connecting the system to the utility grid or storing excess electricity in batteries for use at night or on cloudy days. The performance of a solar cell is measured in terms of its efficiency at converting sunlight into electricity. Only sunlight of certain energy will work efficiently to create electricity, and much of it is reflected or absorbed by the materials that make up the cell. Because of this, a typical commercial solar cell has an efficiency of 15%—only about one-sixth of the sunlight striking the cell generates electricity [11,12]. Low efficiencies mean that larger arrays are needed, and higher investment costs. It should be noted that the first solar cells, built in the 1950s, had efficiencies of less than 4% [13].

III. EXPERIMENTAL SETUP

A thermoelectric (TE) cooler, sometimes called a thermoelectric module or Peltier cooler, is a semiconductor-based electronic component that functions as a small heat pump [1]. By applying a low voltage DC power source to a TE module; heat will be moved through the module from one side to the other. One module face, therefore, will be cooled while the opposite face simultaneously is heated. It is important to note that this phenomenon may be reversed whereby a change in the polarity (plus and minus) of the applied DC voltage will cause heat to be moved in the opposite direction. Consequently, a thermoelectric module may be used for both heating and cooling thereby making it highly suitable for precise temperature control applications. The TEM operating principle is based on the Peltier effect is shown in figure 5. The Peltier effect is a temperature difference created by applying a voltage between two electrodes connected to a sample of semiconductor material to create a hot side and a cold side. The cold side of the thermoelectric module is utilized for air conditioning purposes; provide cooling to the cold space. On the other hand, the heat from the hot side is utilized for heating purpose.

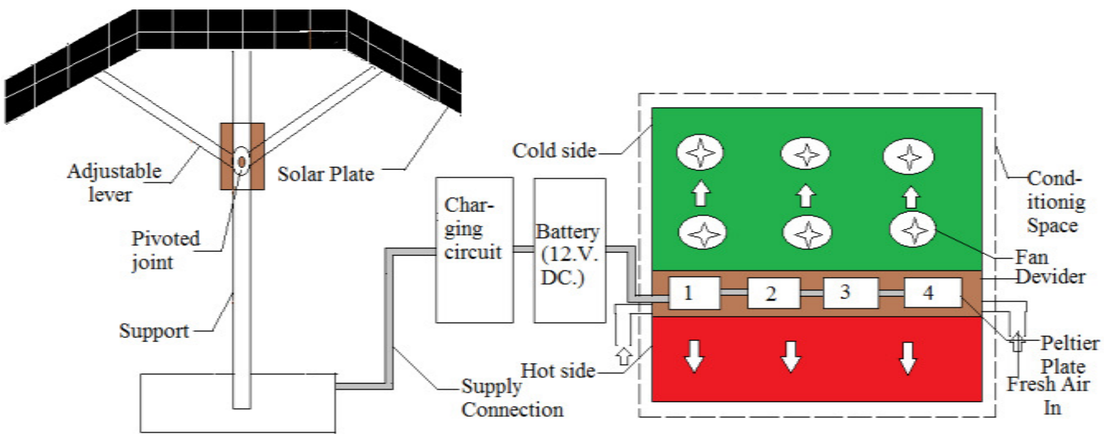

Fig. 5. Experimental Working Model.

A. Construction of Refrigeration System

The construction setup of the refrigerator is as follows: [2]

Thermo-Electric Module. A thermo-electric module (TEM) is a solid state current device in which if power is applied, the heat moves from the cold side to the hot side, acting as a heat exchanger. This direction of heat travel will be reversed if the current is reversed. It is a phenomenon that opposite to the Seebeck effect. A combination of many pairs of P and N semiconductors allows creating cooling units. Peltier modules of relatively of high power. A Peltier module consists of semiconductors mounted successively, which form P-N and N-P junctions. Each junction has a thermal contact with radiators. When switching on the current of the definite polarity, there forms a temperature difference between the radiators one of them warms up and works as a heat sink, and the other work as a refrigerator. A TE module is composed of two ceramic substrates that give foundation and also electrical insulation to p-type and n-type semiconductors. The TE module is composed of Silicon-Bismuth semiconductor because this pair gives the highest COP. Specification of Silicon–Bismuth Material are as:

Area = 0.04 x 0.04 = 0.0016 m^2
Q max =33.3 Watt
V max = 14.8 V DC
I max = 6 Amp

Refrigeration Chamber. The chamber used is same as that of the chambers used in conventional refrigeration. The chamber canbe of any volume, shape and size. For experimentation purposes the volume of the chambers is kept low.

Fig. 6. Refrigeration frame.

The insulation provided to the chamber is done by polystyrene and aluminum casing is done in the innerside of insulation to provide better cooling.

We used specific chamber with the specification:

Size of the box
Width - 28.7 cm
Length - 31.8 cm
Height - 33.7 cm
Power capacity = 60 W.
Capacity of cooling chamber = 7.8 L
Voltage = 240 V to 220 V AC and 12 V DC

Solar Cell. The direct conversion of solar energy is carried out into electrical energy by conversion of light or other electromagnetic radiation into electricity.

Dimensions of the panel are:
Length – 48.5 cm,
Width – 35 cm.
Number of sub-cells used = 72
Dimension of the sub-cells is,
Length – 4.8 cm
Width – 4 cm.
Maximum power = 20 W
Voltage = 17 V
Current = 1.16 A

IV. SIMULATION AND RESULTS

The design of the Peltier device according to specifications has been developed, and algorithm is applied using MATLAB software. PWM is one of thetool that with which we are getting best possible COP. This part presents the information of instruments, working procedure, and operating parameters of the thermoelectric cooler. We use TEC1-127-06L a thermoelectric module. Every specific application where a thermoelectric cooler module or refrigerator is required is characterized by a set of operating 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. the thermoelectric cooler module material is Bismuth telluride. TEC generates Joule heat, it makes heat rejection from TEC hot side, which is called $Q_{H,}$is larger than the heat absorption into the TEC cold side, which is called Q_L. The general forms of heat absorption and heat rejection are presented as bellow. Heat transferred into the cold side when neglect the temperature drop through the TEC is given by:

$$Q_L = [SITc - I^2R - k\ (Th - Tc)] \quad (9)$$

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

$$Q_H = SITh + I^2R - k\ (Th\text{-}Tc) \quad (10)$$

Where
Q_H - heat rejection,
Q_L - heat absorption,
I - Current
R - Electric Resistance
K - Thermal conductivity
Tc - cold side temperature,
Th - hot side temperature,
S - Seebeck co-efficient.

After measuring the temperature by radiation pyrometer, final temperature at the surface of the module and the heat sink are as follows.
Temperature at hot side Th = 68˚ C
Temperature at cold side Tc = 17˚ C

So, Temperature difference can be considered as
T= (Th – Tc) = (68-17) = 51˚C

A. Influence of PWM on Coefficient of Performance

Pulse Width Modulation (PWM) is a nifty current control technique that enables to control the speed of motors, heat output of heaters, and much more in an energy-efficient (and usually quiet) manner.In PWM technique we deal with current supply of system by manipulating duty cycle of circuit we achivesame power in less current supply. This paper applied PWM to analyse the changes in Coefficient of performance (COP).COP is calculated as:

$$COP = Q_L / \text{Energy Supplied} \quad (11)$$

Table 2: COP with and withot PWM.

Without PWM	With PWM
I = 6A	I = 1A
$\Delta t = 51\,^0c$	$\Delta t = 51\,^0c$
COP = 0.40	COP = 1.66

V. CONCLUSION

Currently, the refrigeration system is extensively used as a cooling agent, but it consumes lots of electricity and releases various types of gases like CO_2, CO which is harmful to the atmosphere and produce global warming and climate change. This paper covers all the relevant concerns for the design of refrigeration system using the Peltier device based on solar energy. A portable Heating & Cooling system was fabricated using thermoelectric module & electric control unit & tested for the cooling and heating purpose. The system is self powers & can be used in isolated & a remote part of the country where load-shading is a major problem. This paper use PWM compared to the previous model to enhance the COP. It is clear from the results that the COP with PWM is 1.66, which is much better than the COP without PWM.this concludes that the overall system is enhanced

VI. FUTURE SCOPE

We used PWM for the enhancement of results. Further improvement in the efficiency of the system may be possible through improving module contact-resistance & thermal interfaces. This could be achieved by installing more modules in order to cover a greater surface area of the system. To build a real time model replacing both air conditioner & room heater in one system, i.e. thermoelectric hot & cold room conditioner.

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