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Thermoelectric refrigeration system using solar energy: A review

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ABSTRACT

Refrigerator is an appliance for everyday use in household as well as industries. Most of these works on vapor-compression cycle which uses Chlorofluorocarbons (CFC's) and (Hydro chlorofluorocarbons) HCFC's refrigerants for cooling which causes environmental degradation and high electricity usage (Arjun *et al.*, 2017). Thus, we focus on an alternative and ecofriendly refrigeration system, one of them is solar Peltier refrigeration in which we use natural resources as energy source. The working principle of this method is based on thermoelectric and photovoltaic effect. The working of thermo electric module is based on the peltier effect in which a temperature difference is developed between the two junctions of the thermocouple due to which one side of the peltier becomes cold and other hot. In refrigerator space, cool side of the thermocouple model is used whereas hot side is used for the rejection of heat to atmosphere with the help of heat sink (Deshmukh *et al.*, 2015). Thermoelectric devices are reliable energy converter and have no noise or vibration as there are no mechanical moving parts. Thermoelectric refrigerator acts as solid-state heat pump so, it does not require any refrigerant. Coefficient of performance which is a criterion of performance of such a device is a function of temperature between source and sink. COP of thermoelectric refrigerator is around 0.3-0.5. For maximum efficiency the temperature difference is to be kept to the barest minimum. Finally, our vision for future is use of clean energy from solar energy for thermoelectric refrigeration system.

Keywords: Thermoelectric refrigeration, Peltier effect, Coefficient of Performance, Solar cells

Introduction

Refrigeration is a branch where sciences and engineering involved for solving the mankind's cooling and refrigeration needs in large scale applications from the cooling of electronic devices to food cooling. It involves combination of various disciplines, including mechanical engineering, chemical engineering, chemistry, food engineering, dairy engineering, civil engineering and many more. But refrigeration has most energy consuming operation because of dairy industry refrigeration plant contributes approximately 40 to 50% of total electricity load and it uses CFC's and HCFC's refrigerants which causes environment degradation such as ozone Layer depletion and global warming because refrigeration and air conditioning contributes about 29.6% of the total ozone depletion (Dubey *et al.*, 2017) [1]. So, it is necessary to investigate alternative cooling technologies to the refrigeration like solar refrigeration system using Peltier effect such as solar electric refrigeration system, solar thermal refrigeration system and thermo-mechanical refrigeration system etc. Due to high cost of electrical energy uses, the current trend of the world is to look at renewable energy resources as a source of energy.

The basic idea is implementation of photovoltaic driven refrigerating system powered from direct current source or solar panel with a battery bank using thermoelectric module. Thermoelectric devices are solid-state devices in which electrons or holes equivalent to refrigerants in traditional vapor-compression system carry electricity and thermal energy under an electric field (Elmaaref *et al.*, 2015). Thermoelectric Refrigeration aims at providing 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. Thermoelectric coolers are environmentally safe, much quieter, have no moving parts, almost virtually vibration free and consume less electricity compared to regular refrigerators.

The stability of phase changing materials used in solar thermal storage systems for absorption refrigeration, offering a comprehensive overview of phase changing materials applications within these systems (Patil *et al.*, 2024) [2].

A portable solar-assisted thermoelectric refrigerator, the system basically comprises a photovoltaic module that provides electricity to the thermoelectric module and a well-insulated rectangular aluminum container functioning as the cooling chamber (Rahman *et al.*, 2020) [3].

The main objective of this paper is to give an overview of thermoelectric technology that are available to deliver refrigeration from solar energy.

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Basic principles

Thermoelectric refrigeration works on principle of Peltier effect. Jean Peltier, a French physicist found the Peltier effect in 1934. It is reverse of Seebeck effect. The energy source used for thermoelectric refrigeration here solar cells used which converts solar energy into electric energy.

2.1. Seebeck effect

In 1821, the first important discovery related to thermoelectricity discovered by German scientist Thomas Seebeck who found that an electric when two dissimilar metals are connected in circuit then these two junctions are kept at different temperatures, emf (electromotive force) will generate in circuit. This is known as Seebeck effect and he stated that emf generated is directly proportional to temperature difference (Dhabhi *et al.*, 2012) [4].

$$\Delta E \propto \Delta T \dots\dots(i)$$

Where,

ΔE and ΔT the emf generated and temperature of junction.

2.2. Peltier effect

Peltier effect is reverse of Seebeck effect. In 1834, while investigating the Seebeck Effect, a French watchmaker and part-time physicist, Jean Peltier found that in a pair of dissimilar metals circuit, when direct current is passed through it, there is heating at one junction and cooling at another junction. At the junction between the two dissimilar metals the heat evolved or absorbed in unit time (Q) is proportional to the current (I) (Behera *et al.*, 2022) [5]. Wei He *et al* Conducted did Numerical study of Theoretical and experimental investigation of a thermoelectric cooling and heating system driven by solar. In summer, the thermoelectric device works as a Peltier cooler when electrical power supplied by PV/T modules is applied on it. The minimum temperature 17 °C is achieved, with COP of the thermoelectric device higher than 0.45. Then comparing simulation result and experimental data.

$$Q = \pi ab \times I$$

(ii)

Where,

Q : Heating and cooling effect

π_{ab} : Peltier coefficient

I : Direct current, Amperes

2.3. Photovoltaic effect

Edmund Becquerel discovered the photovoltaic (PV) effect in 1839, when he observed that a voltage and a current were produced when a silver chloride electrode immersed in an electrolytic solution and connected to a counter metal electrode was illuminated with white light. The direct conversion of sunlight into direct current using solar cell. (Joshi *et al.*, 2012) [6]. Concentrating photovoltaic (CPV) system has attracted a great attention as it possesses the highest efficiency of all PV technologies. Sunlight is focused by mirrors or lenses onto the small array of CPV cells (Tayagaki *et al.*, 2019, Green and Bremner *et al.*, 2017) [7].

However, concentrating sunlight inevitably causes heat generation, so it significantly increases the temperature of CPV cells. The high temperature is very detrimental to the performance of solar cells. Band gap reduction and higher recombination rate at a high temperature substantially decrease the open-circuit voltage (V_{oc}) of a solar cell, leading to the degradation of solar cell performance (Skoplaki *et al.*, 2009) [8].

3. Thermoelectric materials

Material used in thermoelectric refrigeration is largely dependent on figure of merit. It is desirable to use the material which has higher value of figure of merit because it leads to higher cooling effect of a thermoelectric module. According to the primary criterion of figure of merit (ZT), a good thermoelectric material should have high Seebeck coefficient, high electrical conductivity, and low thermal conductivity. The formula for figure of merit is given by equation (iii) (Patil *et al.*, 2015) [9]. So, the properties which are considered for selection of thermoelectric material are:

$$ZT = \frac{\alpha^2 \times \delta}{K} \dots\dots\dots(III)$$

Where,

ZT = Figure of merit,

α = Seebeck coefficient,

δ = Electric conductivity,

K = Thermal conductivity

Commonly used thermoelectric materials are Bismuth telluride (Bi_2Te_3), Lead Telluride (PbTe), Silicon germanium (SiGe) and Cobalt antimony (CoSb_3), among which Bi_2Te_3 is the most commonly used one. These materials usually process a figure of merit value less than one.

4. Thermoelectric module

Thermoelectric module consists of p -type and n -type semiconductor which are electrically connected in series and thermally in parallel. These two semiconductors are sandwich between two ceramic substrate that serve as foundation and electric insulation for semiconductor. Due to doping, p -type of semiconductor has deficiency of electron and n -type of semiconductor has excess of electron in their atomic lattice. Then electrically conductive material such as copper pad is connected between ceramic and module to provide electric connection between modules.

When direct current is passed through copper pads to n -type semiconductor to p -type semiconductor. When current flow through n -type to p -type semiconductor which results into cooling effect and current passes through p -type to n -type which results heating effect. The surface where heat is absorbed become cold and surface of opposite junction where heat rejected it become hot. The directions of current are reversing which results in temperature of hot and cold junction also reverse. Similar conceptual design for a grid-interactive solar photovoltaic/thermal-powered cold storage system for potato preservation. Design comprises four primary components: cold storage, a LiBr-water absorption system, solar thermal flat-plate collectors (FPCs), and solar photovoltaic (PV) modules (Basu *et al.*, 2016) [10].

5. Photovoltaic cell

Photovoltaic cells convert some of the absorbed photon energy to electricity, but most of the energy is converted to heat. The generated heat is removed by thermal conduction to the back plane of the cell, to minimize the increase in cell temperature that would lead to reduction in the conversion efficiency of the cell. The heat flux to be removed can be significant in concentrating photovoltaic (CPV) cells, typically exposed to illumination fluxes 500–2000 times higher than natural sunlight. Photovoltaic cell is the basic unit of solar panel which is used to generation of electric energy using solar energy. It is made of two silicon semiconductors and it consists of two semiconductor p and n -type same as thermoelectric module due to doping p -type semiconductor has deficiency of electron and n -type semiconductor has excess of electron. When light strikes on solar panel, electron-hole pairs are generated in semiconductor and try to attain the equilibrium. For attaining equilibrium, negative charge of electrons moves to p -type semiconductor from n -type semiconductor and positive charge holes move to n -type of semiconductor from p -type of semiconductor. This Process is very fast but does not continuous forever after some time there will be layer of negative charge of electron

on the contact surface of *p*-type semiconductor and similarly positive charge holes layer on *n*-type semiconductor contact surface. Due to negative and positive layer on contact surface produce electric field between semiconductors which flow through wire to battery.

6. Thermoelectric refrigeration system using solar energy

PV technology is usually used to provide the power for the solar-driven thermoelectric refrigeration systems. The solar PV/battery thermoelectric refrigeration is first developed. The main components of the system are the PV cell (including the PV array, the storage battery, the controller), the thermoelectric refrigeration system, and the cooled object (e.g., a cooling box). The PV array, which produces DC electricity when exposed to sunlight, is the most expensive component in the system. It is installed outdoors away from shadows, usually in the house roof and tilted towards the equator by an angle equal to the latitude of the location. This stored energy is used for running the refrigerator during nights, cloudy and rainy days. There are specially designed lead-acid batteries suitable for deep discharge cycles occurring in PV systems. The controller is an electronic device, which controls the system operation according to the state of charge of the battery. Its main duty is to protect the battery against excessive charging or discharging. Solar cells are coupled in bigger unit is called solar panel. This solar cell is directly converting sunlight into electricity (Direct current), then that direct current passes through charge controller to battery. Charge controller avoids fluctuation of sunlight on

solar panel, also prevent overcharging and electrical overload of battery. The battery is provided for extra energy storing and required energy is given to thermoelectric module for its working. In thermoelectric module direct current is passes through *n*-type to *p*-type semiconductor which results in cooling effect due to heat absorbed at cold junction become cold. Similarly, at opposite side when direct current from *p*-type to *n*-type semiconductor flow which results in heating effect and it became hot by rejecting heat.

6.1. Factors affecting on performance of the solar refrigeration system using Peltier effect

6.1.1. Figure of merits (ZT) of thermoelectric materials

The formula for maximum efficiency ($\eta_{\max}$) of heat conversion into electricity by a thermoelectric device in terms of the dimensionless figure of merit (ZT) has been widely used to assess the desirability of thermoelectric materials for devices. Figure of merits (ZT) depends only on Seebeck coefficient, electric resistivity and thermal conductivity and to increase thermoelectric module efficiency its properties required maximized. Presently, Bismuth telluride (Bi_2Te_3), which is the best low temperature thermoelectric material and is widely used in thermoelectric generators and coolers. Bi_2Te_3 gives a maximum value 1 of ZT . (Min 2002). If the ZT could be increased to 2 or 3, the thermoelectric cooling device would be competitive with vapor compression cooling systems and if the ZT could be increased to 6, thermoelectric devices would be able to cool to cryogenic temperature (77 K) from room temperature (Riffat *et al.*, 2004) [11].

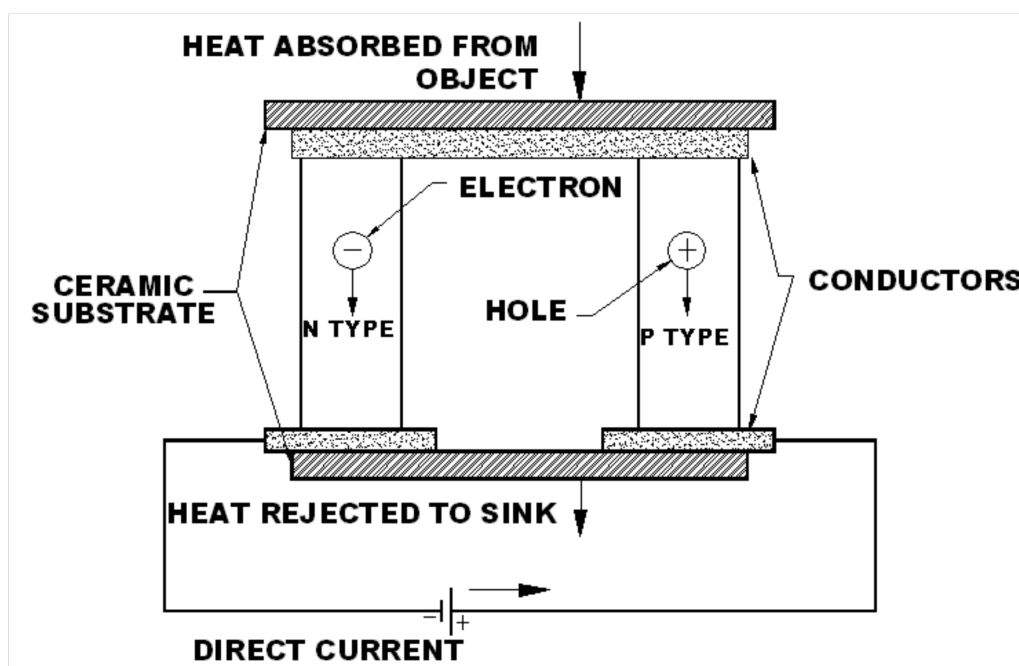


Figure 1. Schematic diagram of a Thermoelectric Module

6.1.2. Temperature difference between hot and cold side

Coefficient of refrigeration (COP) of a thermoelectric module also depends upon module's hot and cold side temperatures, i.e, T_h and T_c , respectively. Increasing the T_c and decreasing the T_h will enhance the COP. For a fixed T_h or T_c , the COP of a thermoelectric module typically decreases with an increase in the temperature difference between the module's hot and cold side. So, temperature difference between the module's hot and cold side is required lower for higher performance. For a typical domestic refrigerator, a temperature difference between the environment and the cabinet of about 25–30K at $T_h = 300\text{K}$ is usually required to achieve acceptable cooling performance. This indicates that the maximum COP of a thermoelectric refrigerator comprise of a commercially available module is around 0.9–1.2 (Riffat *et al.*, 2004) [11]. However, the practically Coefficient of refrigeration of a thermoelectric refrigerator is much lesser than

this because the temperature difference between the hot and cold side of the thermoelectric module and it is higher than the temperature difference between the environment and the cabinet.

The thermoelectric refrigerator consists of a thermoelectric cooling module. The cold side of the module is set inside the refrigerator and the hot side is set outside. A fin-type heat exchanger is tied with the hot side in order to release heat more efficiently. In the module, the electric current flows from N type element to P type element at cold junction, whilst the current flows from P type element to N type one at hot junction, the heat is rejected to the outside at the same time this is the so called Peltier effect.

6.1.3. Thermal resistance of the sink

The efficiency of the heat exchange system strongly influences the cooling performance of the thermoelectric cooling system. If thermal efficiency of the heat exchange is higher in thermoelectric module

and temperature difference between hot and cold side of module is lower which results in higher the performance of cooling. So, for thermoelectric refrigeration system heat exchangers should be designed to minimize their thermal resistance limited such as the size of the system and heat transfer method and system design method, because of the increased in thermal resistance of the heat exchangers, the efficiency of thermoelectric cooling systems reduces. Also, thermal resistance at both sinks due corrosion and wear increases, it decreased the performance. Proper Insulation is essential part of any system where, heat loss required being negligible and for economic performance. In thermoelectric refrigeration system for cooling side is required to properly insulate to reduce the heat loss through cold side to environment.

Advantages of solar refrigeration using Peltier effect

Thermoelectric cooling offers a various advantage over conventional refrigeration methods, such as this system work electrically without mechanical moving part; it eliminates vibration, noise and problems of wear so it maintains ace cost is lower. Thermoelectric refrigeration has high reliability due to its solid-state construction. System uses direct current and by reversing the direction of current transforms the cooling unit into a heater and there is no use of any type of refrigerant so this system is eco-friendly also this system is smaller in size and lighter than convectional refrigeration system. So, this thermoelectric refrigeration system is useful in any orientation and zero gravity.

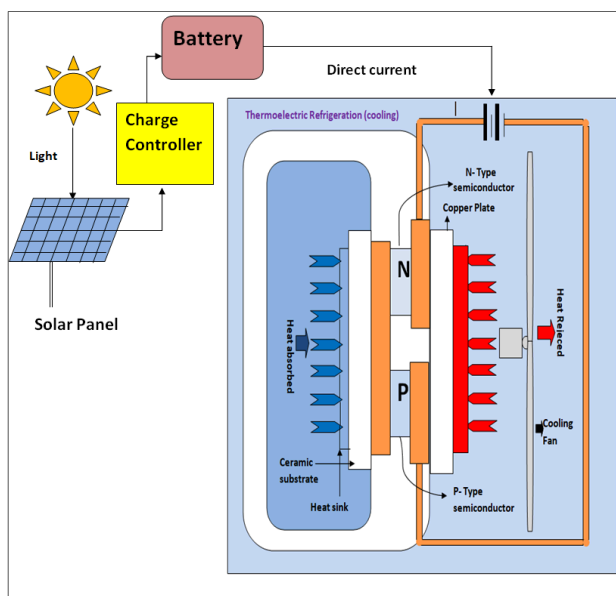


Figure 2. Thermoelectric refrigeration system using solar energy

Disadvantages of solar refrigeration using Peltier effect

Installation cost is high due to use of solar system. Coefficient of refrigeration is less as compared to conventional refrigeration system. Mainly used in low-capacity applications.

7. Conclusions

Solar thermoelectric refrigeration is a novel system which will be a better alternative for convectional system. Solar thermoelectric refrigeration system has long life, less maintenance cost, eco-friendly system and overcomes electricity cost and its problems. The high energy efficiency of thermoelectric module is obtained, when temperature

difference between hot and cold junction is lower. This system is powered by solar energy so used in remote area where electricity supply not provided. So, in future research study, we need to design and increase efficiency of the refrigeration system which is works on solar energy using Peltier effect.

References

1. Dubey A, Singh U, Rathore M. A Study & Analysis of Thermoelectric Refrigeration System with Environment. *International Journal of Engineering Sciences and Research Technology*. 2017;4:259-264.
2. Patil B, Salunke N, Diware V, Ar SR, Ansari KB. Stability assessment of emerging phase change materials for solar thermal storage in absorption refrigeration: A review. *Int. J. Green Energy*. 2024;22:253–280.
3. Rahman SMA, Hachicha AA, Ghenaï C, Saidur R, Said Z. Performance and life cycle analysis of a novel portable solar thermoelectric refrigerator. *Case Stud. Therm. Eng.* 2020;19:100599.
4. Dhabhi BJ, Parmar N, Mehta NS. Consideration for design of thermoelectric refrigeration system. *International Journal of Advanced Engineering Research and Studies*. 2012;1:259-26.
5. Behera D, Sharma R, Ullah H, Waheed HS, Mukherjee SK. Electronic, optical, and thermoelectric investigations of Zintl phase AAg_2Se_2 (A= Sr, Ba) compounds: a first-principle approach. *Journal of Solid State Chemistry*. 2022;312:123259.
6. Joshi D, Selokar N, Nandeshwar K, Rewatkar S. Solar Operated Solid State Refrigeration Using Peltier effect. *International Journal of Enhanced Research in Science Technology and Engineering*. 2012;8:1-12.
7. Tayagaki T, Araki K, Yamaguchi M, Sugaya T. Impact of nonplanar panels on photovoltaic power generation in the case of vehicles. *IEEE Journal of Photovoltaics*. 2019;9(6):1721-1726.
8. Skoplaki E, Palyvos JA. On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. *Solar energy*. 2009;83(5):614-624.
9. Patil S, Devade K. Review on Thermoelectric Refrigeration: Applications and Technology. *International Journal of Modern Trends in Engineering and Research*. 2015;2:119-129.
10. Basu DN, Ganguly A. Solar thermal–photovoltaic powered potato cold storage—Conceptual design and performance analyses. *Appl. Energy*. 2016;165:308–317.
11. Riffat SB, Xiaoli M. Improving the coefficient of performance of thermoelectric cooling systems: a review. *International journal of energy research*. 2004;28:753–768.
12. Min M, Askalany A, Salem M. Solar Thermoelectric Cooling technology. *Proceedings of 3rd International Conference on Energy Engineering*. 2015:1-5.
13. Green MA, Bremner SP. Energy conversion approaches and materials for high-efficiency photovoltaics. *Nature materials*. 2017;16(1):23-34.
14. Sharma A, Agrawal A, Shrivastava N. Solar Energy Based Refrigeration Using Peltier effect. *International Journal of Theoretical and Applied Sciences*. 2018;1:110-116.

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