Experimental Study of Solar Powered Heating and Cooling System Using Thermo-Electric Module

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Abstract:

Experimental study of solar powered heating and cooling system using thermo-electric module has been conducted. Research interest focused on testing the system performance under sunshine. The main objective of this study is to design and build an affordable solar thermoelectric refrigerator for the Bedouin people (e.g. deserts) living in remote parts of Oman where electricity is still not available. Experiment results demonstrated that the unit could maintain the temperature in the refrigerator at 15 – 18 oC, and have a COP about 0.25. Further analysis indicated that the performance of the system is strongly dependent on intensity of solar insolation and temperature difference of hot and cold sides for the thermoelectric module, etc. There exist optimum solar insolation rates, which let the cooling production and COP achieve maximum value, respectively. It was expected that the refrigerator would be potential for cold storage of vaccine, food and drink in remote area, or outdoor conditions where electric power supply is absent.

Keywords

Thermoelectric module, solar panel, battery, digital thermometer , etc.

1. Introduction

Solar thermoelectric refrigerator is a special type of refrigerator which utilizes solar energy instead of conventional electrical energy to power the thermoelectric module that has been used to cool the refrigeration space. B.J. Haung, et al. (1) Conducted experimental study of design method of thermo electric cooler. They are fabricated the thermoelectric cooler and analyses various considerations. The system simulation shows that there exists a cheapest heat sink for the design of a thermoelectric cooler. It is also shown that the system simulation coincides with experimental data of a thermoelectric cooler. Astrain, yadav et al (3-4) conducted an experimental investigation of the COP in the thermoelectric refrigeration by the optimization of heat dissipation. Bansal , Manoj, Min et al. (5-7) investigate and compared the performance characteristic of their domestic refrigeration namely the vapour compression the thermoelectric and the absorption refrigeration based on actual experimental data. In this present paper, a design for portable solar thermoelectric refrigerator was presented and tested experimentally.The main objective of the refrigerator service is to be suitable for use by the Bedouin people who live in the remote areas of Oman where electricity is not available. The refrigerator can also be used for remote parts of the world or outer conditions where electric power supply is not readily available.

2. Components of the solar thermo-electric refrigerator

The major components of the solar thermoelectric refrigerator include: thermoelectric module, solar cells, aluminum box, plastic plates, finned surface (or heat sink), and the cooling fan. In this study, 2 thermoelectric modules were used in the design of the refrigerator. Fig. 1 depicts one of the 2 modules that were used. Looking at Fig. 1, it can be seen that the module comes with two wires. Table 1 shows the specifications of the thermoelectric module used in this study. The electrical power generated by the solar cells was supplied to the thermoelectric refrigerator by means of the photovoltaic effect. The solar cells used in this study were manufactured by BP Solar. In addition, aluminum sheets were added to the sides of the cabinet of the refrigerator to evenly distribute the cold for a uniform temperature within the whole refrigerator. The plastic plates were used as thermal insulation for inhibiting the back flow of heat when operating in humid conditions. They also used to prevent any loss in the performance of the refrigerator to be affected by external heat which is important when refrigerator is used in hot conditions (e.g. Bedouin desert). The finned surface (i.e., heat sink) was used to enhance and increase the rate

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of heat transfer from the hot surface of the thermoelectric module so the heat will be discarded outside of the refrigerator. In order to maintain the efficiency of the thermal module, cooling fanwas used to reject the heat from the hot side of the module to ambient surroundings.

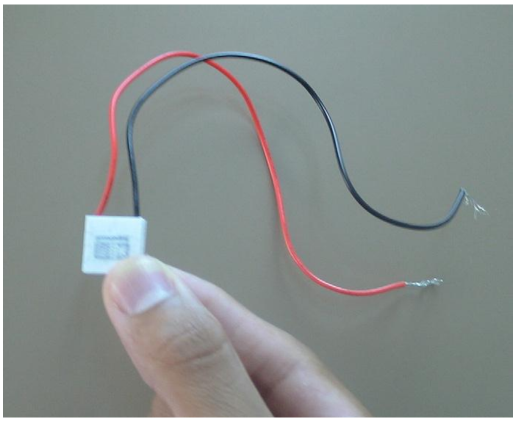

Fig. 1. Thermoelectric module with two wires.

3. Construction

Here this system heat or cool the product using Thermo-electricmodule.the construction set up for this system require following parts

1. Solar panel 2.Charge controller
3. Battery 4.Fins, thermister
5. Exaust fan circuit kit
6. Thermoelectric module.
7. Metal (aluminium box, sheets)

A. Solar Panel

The direct conversion of solar energy is carried out into electrical energy by means of the photovoltaic effect i.e. the conversion of light or other electromagnetic radiation into electricity. Heat can be converted directly into electrical energy by solar cell, more generally a photovoltaic cell.

The solar panel use in this fabrication having an input capacity 16v and output capacity 21v.

B. Charge Controller

The charge controller is a simple,efficient and precise controller designed to operate with the charge source such as solar panels and wind generator to prevent overcharge.

Output drive current-1.0 Amps.

C. Battery

The battery is an electrochemical device for converting chemical energy into electrical energy. The main purpose of the battery is to provide a supply of current for operating the cranking motor and other electrical units.

Capcity of battery-12v.

D. Thermoelectric Module

A typical thermoelectric module is composed of two ceramic substrates that serve as a foundation and electrical insulation for P-type and N-type Bismuth Telluride dice that are connected electrically in series and thermally in parallel between the ceramics. The ceramics also serve as insulation between the modules internal electrical elements and a heat sink that must be in contact with the hot side as well as an object against the cold side surface. Electrically conductive materials, usually copper pads attached to the ceramics, maintain the electrical connections inside the module. Solder is most commonly used at the connection joints to enhance the electrical connections and hold the module together [6]. Most modules have and even number of P-type and N-type dice and one of each sharing an electrical interconnection is known as, "a couple." [6]. While both P-type and N-type materials are alloys of Bismuth and Tellurium, both have different free electron densities at the same temperature. P-type dice are composed of material having a deficiency of electrons while N-type has an excess of electrons. As current (Amperage) flows up and down through the module it attempts to establish a new equilibrium within the materials. The current treats the P-type material as a hot junction needing to be cooled and the N-type as a cold junction needing to be heated. Since the material is actually at the same temperature, the result is that the hot side becomes hotter while the cold side becomes colder. The direction of the current will determine if a particular die will cool down or heat up. In short, reversing the polarity will switch the hot and cold sides [7].

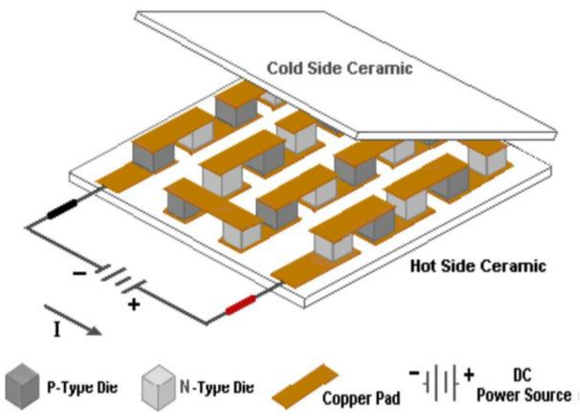

Figure 2: Internal construction of thermo- electric module (adapted from ADVANCED THERMOELECTRIC · One Tara

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4. How it works

When two conductors are placed in electric contact, electrons flow out of the one in which the electrons are less bound, into the one where the electrons are more bound. The reason for this is a difference in the so-called Fermi level between the two conductors. The Fermi level represents the demarcation in energy within the conduction band of a metal, between the energy levels occupied by electrons and those that are unoccupied.

When two conductors with different Fermi levels make contact, electrons flow from the conductor with the higher level, until the change in electrostatic potential brings the two Fermi levels to the same value. (This electrostatic potential is called the contact potential.). Current passing across the junction results in either a forward or reverse bias, resulting in a temperature gradient. If the temperature of the hotter junction (heat sink) is kept low by removing the generated heat, the temperature of the cold plate can be cooled by tens of degrees (figure 2).

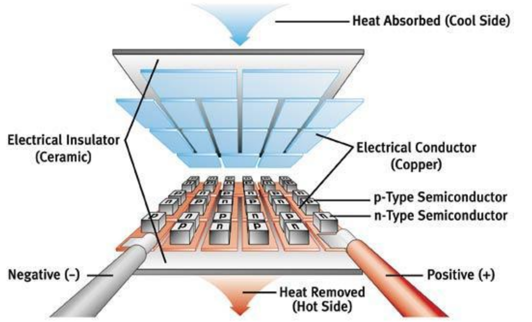


Fig.3 TEC Construction

Table 1

Specifications of the thermoelectric module used in our project

Sr.no.	specification	value
1	Maximum current (A)	5
2	Maximum voltage(V)	12
3	Maximum temperature(°c)	58
4	Dimension in (L×W×H)mm	40×40×3.4
5	Number of couples(N)	2

5. Configuration of the thermoelectric refrigerator

In this section, an experimental investigation and performance analysis on solar thermoelectric refrigerator was conducted.

Table 2

Example of results obtained from running one of the experiments
Ambient temperature = 34.4°c

no	Current (A)	Voltage (V)	Temp. cold side (°C)	Temp. hot side(°C)	time (min)	Temp. diff (°C)
1	12	2.4	24.0	40.2	11	16.2
2	12	3.0	21.2	42.0	13	20.8
3	12	3.6	19.0	44.3	20	25.3
4	12	4.0	17.0	45.0	22	28.0
5	12	4.3	16.9	46.4	28	29.5
6	12	4.7	16.7	46.8	35	30.1
7	12	5.0	16.6	47.2	42	30.2

6. Calculation

Calculation of the power consumed by the 10 modules used in the prototype
Each module takes a maximum of 2.5 A and 2 V.
The power needed to give maximum cooling efficiency=2.5×2=5W
The total power consumed by the 2 module units= 2×5=10W.
Calculation of the power consumed by the fans
Each fan consumed 0.5W.
Two fans consumed 1W.
Total power needed from solar cells
Total power= power consumed by the modules+power consumed by fans = 10+1=11W

6.1 Testing the performance of the solar thermoelectric refrigerator

When the designed solar thermoelectric refrigerator was tested, it was found that the inner temperature of the refrigeration area was reduced from 34.4°C to 16.6°C in approximately 18 min, a difference of 17.8°C. Below is an example, which shows how the coefficient of performance of the refrigerator (COPR) was calculated. water (density = 1 kg/L and C =4.18 kJ/kg).

V= 0.5 l canned drink.

Calculation of cop_R --

$Cop_R = Q_{cooling} / W_{i/p}$

m = v = 1(kg/l)×(0.5) = 0.5 kg

$Q_{cooling}$ = mcdT = 0.5 × 4180 × (34.4 – 16.6) = 37202 J

$Q_{cooling}$ =37202 / (60×42) = 14.76 W
$W_{in} = IV$ = 5× 12 = 60W
COP_R = 14.76 / 3-=.25

7. Results and discussion

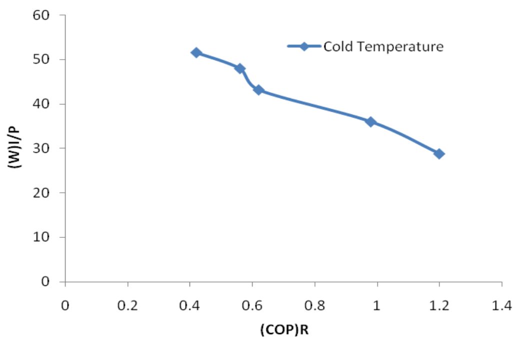
Table 3

Ambient temperature (T_1) = 34.4°C

TDC= temperature difference cold
TDH= temperature difference hot

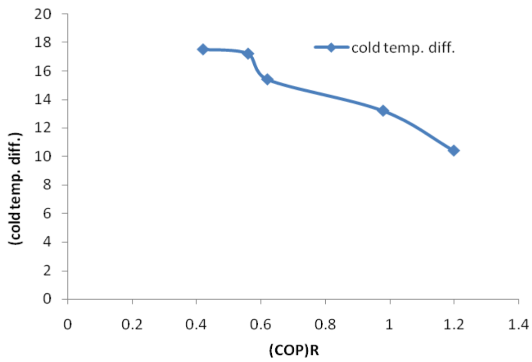
no	$W_{i/p} = V \times I$	Temp. cold side (°C)T_2	Temp. hotside (°C)T_3	Time (min)	TDC (T_1-T2) (°C)	TDH T1-T3 (°C)	COP_R
1	28.8	24.0	40.2	11	10.4	5.8	1.2
2	36	21.2	42.0	13	13.2	7.6	0.98
3	43.2	19.0	44.3	20	15.4	9.9	0.62
4	48.0	17.0	45.0	22	17.2	10.6	0.56
5	51.6	16.9	46.4	28	17.5	12	0.42

7.1. Work input v_s cop_R



We were doing experiments note down reading cop v_s work input and draw this graph. In this graph we use cop and work input . graph show COP decreases from 1.2 to 0.42 and work input increases from 28.8 to 51.6 within 60W. The efficiency of cooling chamber 0.78/22.8= 0.03

7.2 Cold temp v_s cop_R



We were doing experiments note down reading cop vs cold temperature difference and draw this graph. In this graph we use cop and cold temperature difference. Graph show cop decreases from 1.2 to 0.42 and temperature increases from 10.4 to 17.5 .The efficiency of cooling chamber 0.78/7.1 = 0.10.

8. Application

1. It can be uses as remote place where electric supply is not available.
2. In restaurants /hotels
3. At public places
4. Laboratory, scientific instruments, computers and video cameras.
5. Medical and pharmaceutical equipment.
6. Military applications.

8.1. Advantages

Thermoelectric cooling devices and systems are believed to be as good as compressor- o absorber based refrigerators. However we believe that thermoelectric cooling offers a number of advantages over traditional refrigeration ,namely:

1. Solid state heat pumps have no moving parts,
2. No Freon's or other liquid or gaseous refrigerants required,
3. Noiseless operation,
4. Compact size and light weight makes TEMs well suited for miniature coolers,
5. High reliability - We guarantee 200,000 hours of no failures,
6. Precise temperature control,
7. Relatively low cost and high effectiveness,
8. Operation in any orientation,
9. Easy to clean aluminum interior,
10. Eco-friendly C-pentane, CFC free insulation.

9. Conclusion

In this work, a portable solar thermoelectric refrigerator unit was fabricated and tested for the cooling purpose. The refrigerator was designed based on the principle of a thermoelectric module to create a hot side and cold side. The cold side of the thermoelectric module was utilized for refrigeration purposes whereas the rejected heat from the hot side of the module was eliminated using heat sinks and fans. In order to utilize renewable energy, solar energy was integrated to power the thermoelectric module in order to drive the refrigerator. Furthermore, the solar thermoelectric refrigerator avoids any unnecessary electrical hazards and provides a very environmentally friendly product. In this regard, the solar thermoelectric refrigerator does not produce chlorofluorocarbon (CFC), which is believed to cause depletion of the atmospheric ozone layer. In addition, there will be no vibration or noise because of the difference in the mechanics of the system. In addition the rejected heat from the solar thermoelectric refrigerator is negligible when compared to the rejected heat from conventional refrigerators. Hence, the solar thermoelectric refrigerator would be less harmful to the environment. Several tests were carried out with the prototype to determine the minimum temperature that a refrigerated object could be reached. A canned drink with fixed volume was used as the refrigerated object in these tests. Experiment and analysis on the prototype were conducted mainly under sunny outdoor conditions. It was found that the system performance was strongly dependent on the intensity of solar insulation and the temperature difference of hot and cold sides between the thermoelectric modules. The maximum temperature difference under outdoor conditions was found to be 30^{o}c. The energy efficiency of solar thermoelectric refrigerators, based on currently available materials and technology, was still lower than its compressor counterparts. Nevertheless, a marketable solar thermoelectric refrigerator would be made with an acceptable performance through some improvements. For example, further improvement in the COP may be possible through improving module contact-resistance, thermal interfaces and heat sinks. In addition, this could be achieved by including more modules in order to cover a greater surface area of the refrigeration box.

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