EXPERIMENTAL ANALYSIS OF SOLAR POWERED THERMOELECTRIC REFRIGERATOR

[1]NISHAN SHETTY, [2]LAVESH SONI, [3]SAAGAR MANJUNATH, [4]GOVIND RATHI

[1,2,3,4]Department of Mechanical Engineering, DayanandaSagar College of Engineering, Bangalore,India
E-mail: [1]nishan22@hotmail.com, [2]soni.lavesh@gmail.com, [3]saagar1727@gmail.com, [4]govind_rathi@rocketmail.com

Abstract— The global increasing demand for refrigeration, led to production of more electricity and consequently more use of chlorofluorocarbons (CFCs) which acts as a contributing factor in the depletion of ozone layer.

Thermoelectric refrigeration is new alternative because it can convert waste electricity into useful cooling. Therefore, thermoelectric refrigeration is greatly needed, particularly for developing countries where long life and low maintenance are needed.

The objective of this study is to design and develop a working thermoelectric refrigerator that utilizes the Peltier effect to refrigerate and maintain a selected temperature upto 10 °C. The requirements are to cool this volume to temperature within a time period of 2 hours and provide retention of at least next half an hour.

Our project also utilizes the solar energy to run a thermoelectric system. In this project we have fabricated a thermoelectric system using both solar power and electrical power supply. The project has various applications like, food preservation, military or aerospace, medical and pharmaceutical equipment.

Index Terms— Peltier effect, Module, Thermoelectric, Solar powered, Heat flow, Coefficient of Performance.

I. INTRODUCTION

In recent years, with the increasing awareness towards environmental degradation caused by CFCs and HCFCs from refrigerants in conventional refrigeration systems, it has become a subject of due concern. Besides, rural areas won’t have to rely as much on power from the grid for their refrigeration and cooling needs, by harnessing the inexhaustible solar energy to power the thermoelectric refrigeration (TER) system. Also, in situations where efficiency is a less important issue than small size, low weight and high reliability, thermoelectric refrigeration systems would be the preferred choice.

Researchers are continuously striving towards the development of eco-friendly refrigeration technologies like thermoelectric, adsorption, magnetic and thermoacoustic refrigeration.

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. This effect is commonly used in camping and portable coolers and for cooling electronic components and small instruments.

Applying a DC voltage difference across the thermoelectric module, an electric current will pass through the module and heat will be absorbed from one side and released at the opposite side. One module face, therefore, will be cooled while the opposite face simultaneously is heated.

On the other hand, maintaining a temperature difference between the two junctions of the module, a voltage difference will be generated across the module and an electrical power is delivered.

II. BASIC PRINCIPLES INVOLVED IN THERMOELECTRIC COOLING

2.1 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.

The Seebeck 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

Thermoelectric power supply generators are based on the Seebeck effect which is based on voltage generation along a conductor subjected to a gradient of temperature. When a temperature gradient is applied to a conductor, an electromotive force is produced. The voltage difference generated is proportional to the temperature difference across the thermoelectric module between the two junctions.

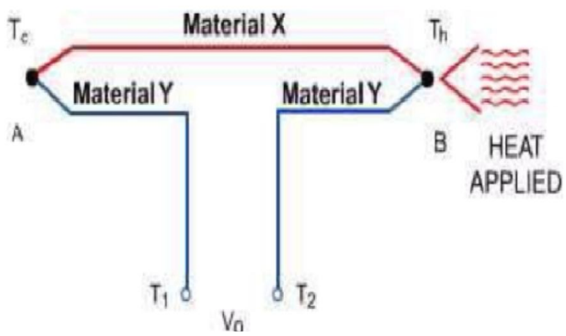

Figure 1: Schematic Representation of Seebeck Effect

2.2 Peltier Effect

It states that ”when an electric current flows across two dissimilar conductors, the junction of the conductors will either absorb or emit heat depending on the flow of the electric current”. The heat absorbed or released at the junction is proportional to the input electric current. The constant of proportionality is called the Peltier coefficient.

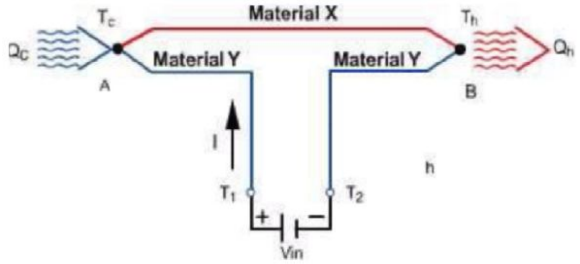

Figure 2: Schematic Representation of Peltier Effect

When a current is made to flow through a junction between two conductors A and B, heat may be generated (or removed) at the junction. The Peltier heat generated at the junction per unit time, Q, is equal to;

$$Q \alpha I$$

$$Q = \pi_{ab} I$$

$\pi_{ab} = \pi_a - \pi_b$ where (π_a & π_b) is the Peltier coefficient of conductor A & B, and I is the electric current (from A to B).

III. EXPERIMENTAL SECTION

In the battery (12V, 7Ah) circuit, the solar panels absorb the sunlight and convert into electricity. The output voltage of the solar panel is 12V (depending on the direction of sunlight). This electricity is utilized for charging the 12V battery which is connected after the solar panel. From the battery, current flows directly into A.C/battery conversion switch and then into the Peltier module. In the AC mains circuit, a two pin plug is inserted into socket mains and is connected to the SMPS circuit/rectifier circuit. We get 240V AC current from the mains, but the peltier assembly (peltier module and cooling fan) requires only 12V and should be DC current. Hence the SMPS circuit is used here. The conversion of AC current into DC current is done by the full wave rectifier. By using a series of capacitor and step down transformer, the voltage is brought down to 12V DC current. After the conversion, it goes into the AC/Battery conversion switch and then into the Peltier assembly.

Figure 3: Fabricated Solar Powered Thermoelectric Refrigerator

Refrigerated container has inner dimensions of (15cm × 17cm × 21cm). It is made of aluminium sheet of thickness 2mm. Then the edges were welded to form a box. For insulation purposes, 10mm thick polystyrene foam (thermocol) is attached to the outer surface of the aluminium box. To keep the thermocol attached to the box, duct tape is wrapped around the thermocol, to ensure that it is packed tightly. The door is also made of thermocol sheet and is wrapped using duct tape. The peltierassembly (includes peltier module, heat sink and cooling fan) is attached to the base of the refrigeration container using four screws. These screws also act as a junction between container and the module. Finally, the components of the prototype are fixed to the wooden base using the hot plastic gun. It ensures that the components do not move from their respective positions. Figure 3 shows final developed solar powered thermoelectric refrigerator.

3.1. Temperature vs Time Readings

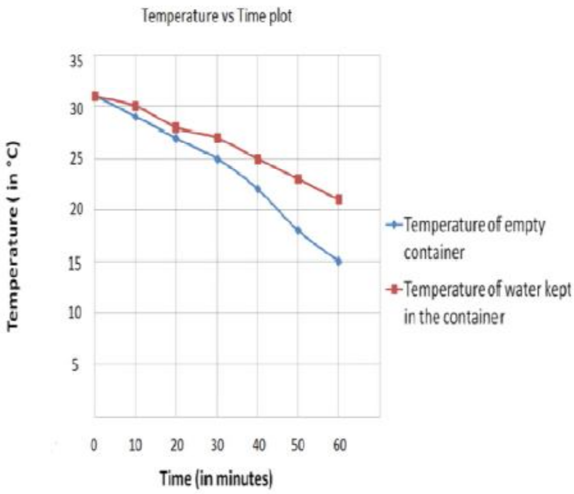

Figure 4: Temperature vs Time plot for empty container and 250 ml water

For performance evaluation of thermoelectric peltier module, experiments were conducted. The temperature drops were observed every 10 minuteswith respect to 31°C ambient temperatureupto an hour for empty container as well as 250 ml water inside container. Readings were tabulated and represented in Temperature vs Time plot (figure 4).

3.2. Heat flow from Surroundings to Container

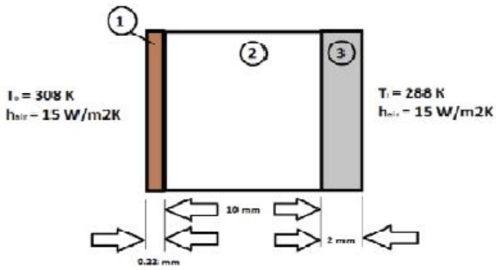

Figure 5: Cross section of wall of refrigeration container

From figure 5,

① represents the cross section of the duct tape (thickness = 0.22mm). Thermal conductivity of duct tape (k_{tape}) = 1.2 W/m K

② represents the cross section of the thermocol (thickness = 10mm). Thermal conductivity of thermocol($k_{thermocol}$) = 0.033 W/m K

③ represents the cross section of aluminium sheet (thickness = 2mm). Thermal conductivity of aluminium(k_{Al}) = 205 W/m K

Next, heat flow from surrroundings to the container was found by,

$$q = \frac{(T_o - T_i)}{R}$$

From the diagram,

$$R = \frac{1}{h_{air}} + \frac{L_{tape}}{k_{tape}} + \frac{L_{thermocol}}{k_{thermocol}} + \frac{L_{Al}}{k_{Al}} + \frac{1}{h_{air}}$$

$$U = \frac{1}{R}$$

3.3 Heat Removed from the Refrigeration Container Using Peltier Module

The heat removed from the refrigeration container using the peltier module was then calculated by,

$Q = m_{air} \times C_{air} \times \Delta T$

where$m_{air} = v \times \boldsymbol{\rho}_{air}$

3.4 Heat removing capacity of Peltier module

Next the heat removing capacity of Peltier module was calculated by,

$$Q_c = (\propto_m \times T_c \times I) - \left(\frac{1}{2} \times I^2 \times R_m\right) - (K_m \times (T_h - T_C))$$

Where,

$$\propto_m = \frac{V_{max}}{T_h}$$

$$R_m = \frac{(T_h - \Delta T_{max})}{T_h} \times \frac{V_{max}}{I_{max}}$$

$$K_m = \frac{(T_h - \Delta T_{max})}{2\Delta T_{max}} \times \frac{(V_{max} \times I_{max})}{T_h}$$

IV. RESULTS

In this experimental analysis, one thermoelectric peltier module (TEC1-12706) was used in fabrication of thermoelectric refrigeration container. The peltier module specifications are I_{max}=6.4A, V_{max}=14.4V and ΔT_{max}=66°C at T_h=25°C and the dimensions of the module are 40mm x 40mm x 3.9mm. The fundamental characteristics of the device were calculated and the values are,

$\propto_m$ *= 0.05077 V/K*R_m *= 0.1983* Ω

K_m *= 0.01167 W/K*

The heat removing capacity of peltier module was thus found to be,

Q_c *= 75.996 J*

The thermal resistance, overall heat transfer coefficient and heat flow were found using the relevant equations to be,

R = 0.4365 m^2 *K/W*$U = \frac{1}{R}$ *= 2.290* $W/m^2$$q$ *= 4.58197* $\times 10^{-5}$ W/mm^2

Next the mass of air in container and heat removed from container using peltier module were calculated to be,

$m_{air} = 6.56 \times 10^{-3}$ *kg*

Q = 105.4848 J

Finally the Coefficient of Performance (COP) was calculated for 250 ml water inside container and was found to be 0.095.

$COP = \frac{Q_{active}}{W} = 0.095$

Where,

$$Q_{active} = \frac{m \times C \times \Delta T}{dt} W$$

$$= \propto_m \times I \times (T_h - T_c) + I^2 \times R_m$$

Where W is the work done.

CONCLUSION

A portable thermoelectric refrigeration system 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 heat from the hot side of the module was eliminated using heat sinks to absorb the heat and fans to reject it. 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 an environmentally friendly product. In this regard, the solar thermoelectric refrigerator does not produce CFCs and HCFCs 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.

The experimental results of developed prototype of TER system shows a 10°C temperature reduction at 250ml water inside refrigeration space of developed TER has been experimentally found with respect to 31°C ambient temperature in 60 minutes. Also the calculated COP of thermoelectric refrigeration cabinet was 0.095. The refrigeration cabinet itself has been experimentally shown to have a 16°C reduction in temperature with respect to 31°C ambient temperature in 60 minutes.

Also it has been experimentally found that the developed TER system can continuously work for 3 hours when the battery is fully charged with solar panel. 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 of COP can be achieved with use of increased figure in merit peltier modules. The efficiency of the system may also be further improved by through improving module contact resistance, thermal interfaces and heat sinks. This can be achieved by installing more modules in order to cover a greater surface area of the system.

Nomenclature

CFCs	:	Chlorofluorocarbons
HCFCs	:	Hydrochlorofluorocarbons
DC	:	Direct Current
AC	:	Alternating Current
SMPS	:	Switched mode power supply
R	:	Thermal resistance, m^2K/W
T_o	:	Outer surface temperature, ^oC
T_i	:	Inner surface temperature, ^oC
L	:	Length, m
h	:	Heat transfer coefficient, W/m^2K
U	:	Overall heat transfer coefficient, W/m^2K
m_{air}	:	Mass of air present, kg
v	:	Volume of container, m^3
ΔT	:	Temperature difference, ^oC
C_{air}	:	Specific heat of air, J/kg^oC
T_h	:	Hot junction temperature, ^oC
T_c	:	Cold junction temperature, ^oC
I	:	Electric current, Ampere
R_m	:	Device electrical resistance, Ω
K_m	:	Thermal Conductance, W/K
V	:	Voltage, V
Q_{active}	:	Active heat load, W
W	:	Work done, W

Greek Letters

$\propto_m$	:	Seebeck voltage, V/K
$\boldsymbol{\rho}_{air}$	:	Density of air, kg/m^3

REFERENCES

[1] Swapnil S. Khode, Pratik Kale, ChandrakantGandhile, "Review on application of thermoelectric peltier module in cooling and power generating technology", International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-3, Issue-1, pp. 71-74, January 2015

[2] Manoj Kumar Rawat, Prasanta Kumar Sen, HimadriChattopadhyay, SubhasisNeogi, "Development and experimental study of solar powered thermoelectric system", International Journal of Engineering Research and Applications, Vol. 3, Issue 4, pp. 2543-2547, Jul-Aug 2013

[3] Sabah A. Abdul-Wahab, Ali Elkamel, Ali M. Al-Damkhi, Is'haq A. Al-Habsi, Hilal S. Al-Rubai'ey', Abdulaziz K. Al-Battashi, Ali R. Al-Tamimi, Khamis H. Al-Mamari, Muhammad U. Chutani, "Design and experimental investigation of portable solar thermoelectric refrigerator", Renewable Energy 34,pp. 30-34, 2009

[4] SurithNivas M, Vishnu Vardhan D, Raamkumar PH, Sai Prasad S, Ramya.K,. "Photovoltaic Driven Dual Purpose Thermoelectric Refrigerator for Rural India", International Journal of Advancements in Research and Technology, Volume 2, Issue 6, ISSN 2278-7763, pp. 111-116, June 2013

[5] Francis J. DiSalvo, "Thermoelectric cooling and power generation", Science 30,Vol. 285, Issue 5428, DOI: 10.1126/science.285.5428.703, pp. 703-706, July 1999

[6] Manoj B. Dhawade, EktaMourya, AnuragYadav, David Samuel, Suprabhat A. Mohod, Vaibhav N Deshpande, "Review on portable solar thermoelectric refrigerator cum air cooler", International Journal of Advance Research in Science and Engineering, Vol. No.4, Issue 10, ISSN: 2319-8354, pp. 44-58, October 2015

[7] Umesh V. Sangale, Prof. PriyankaJhavar, Dr.G.R.Seloskar.S, "Thermoelectric Refrigeration by Using Solar Energy for Domestic Appliance", International Journal of Research in Advent Technology, Vol.3, No.1, E-ISSN: 2321-9637, pp. 72-75, January 2015

★★★