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Fabrication of Thermo Electric Module for Cooling and Heating Applications Using Solar Energy

P. Amaanath[1], K. Kalyani Radha[2]

[1]M.Tech student, Dept of Mechanical Engineering JNTUACEA Ananthapur, India [2]Assistant Professor of Mechanical Engineering JNTUA College of Engineering, Ananthapur, India

Abstract: ***Thermo-Electric refrigeration is one of the recent developments in the field of refrigeration. The development of semiconductor technology enhanced the feasibility of Thermo-Electric applications to greater extent. Thermo-Electric refrigeration systems were worked based on the principle of Peltier effect, where the passage of direct electric current through the junction of two dissimilar semiconductor materials causes the junction to either cool down (absorbing heat) or warm up (rejecting heat) depending on direction of current. In the process of Thermo-Electric refrigeration the cooling effect was effectively utilized but heat energy developed by module is dissipated to environment. Now a day's energy conservation plays a major role in day to day life due to energy crisis. Hence a solution has to be given to utilize the heat energy dissipated to environment for the useful heating applications and conserve waste heat energy. A novel idea of this is to utilize both heating and cooling effects generated by Thermo-Electric module. Cooling effect can be used for storage purpose and the waste heat energy for heat storage and used as hot pack. The power is given by both house hold supply and by solar energy for Thermo-Electric system for heating and cooling applications.***

Keywords: Thermo-Electric Refrigeration, Peltier effect, solar energy, cold storage, Thermo-Electric module.

1. Introduction

The term refrigeration refers to cooling an area or substance below the environmental temperature, the process of removing heat. There are number of methods by which the refrigeration can be achieved. They are broadly classified into two categories: Non-Cyclic and Cyclic methods of Refrigeration. Non-cyclic refrigeration process consists of ice refrigeration and dry ice refrigeration. Cyclic process of refrigeration consists of vapour compression cycle, vapour absorption cycle, gas refrigeration cycle, thermo electric refrigeration etc...

1.1 Thermo-Electric refrigeration

TER (Thermo Electric Refrigeration) modules were made up of two dissimilar metals that can be formed a junction in the 18^{th} century. The developed TEC modules were comes into existence after the invention of semiconductor technology. The concept of See beck effect enhances the thermo electricity which was discovered by Thomas See beck, a German scientist in 1821. The See beck effect states that "when two different conducting materials form a junction together and if we maintain a temperature difference across the junction, then an electric current flow in a closed circuit formed by two materials through the junction". Another scientist named Jean Peltier found an opposite reaction to See beck effect, that was Peltier effect in 1834, which states that "the temperature difference occurs across the junction formed by two dissimilar conducting materials, when a Direct electric Current flows through the junction". The module also called as peltier module and it produces heat on one side and cooling effect on other side when a Direct electric Current flows through it. This peltier effect can be used for refrigeration purpose. Applications for thermoelectric modules cover a wide spectrum of product areas. These include equipment used by military, medical, industrial, consumer, scientific/laboratory, and telecommunications organizations.

2. Operating Principle

The operating principle of the TE modules is the peltier effect which states that "If the DC electric current flows through the junction of two dissimilar semiconductors, there is a temperature difference occurs across the junction". The TE module produces cooling effect on one side and heating effect on other side when a DC current flows through the TE module. If the current direction changes, then the heating and cooling effects are also reversed means that the cooling effect occurs in place of heating effect and heating effect occurs in case of cooling effect. The TE module produces heating and cooling effects based on the current direction. The cooling effect and heating effects are also depends on the magnitude of DC current flows through the TE module. Formation of heat transfer occurs in the direction of current flow. By applying the current to the junction, then it transports heat from hot junction to cold junction. The peltier effect is opposite to see beck effect in which, by applying temperature difference across the junction of two dissimilar semiconductor materials produces electric current.

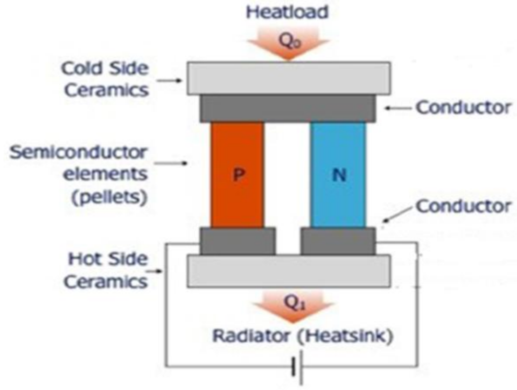

Figure 1: Operating principle of TE module

When DC power is applied to the TEC module, heat is moved from the cold surface to the hot surface. The direction in which the heat is pumped is directly related to the direction of the current. When the direction of the current is reversed, the direction in which the heat is pumped is also reversed. This phenomenon is known as the Peltier Effect and it is the inverse of the Seebeck Effect (Godfrey et al., 1996).

Before 1950, the COP of TEC modules is only about 1%. Semiconductor materials were discovered in 1950, which lead to the improvement in the COP. The semiconductors have a much lower thermal conductivity than metals so that the COP is improved up to 20% (Flurial et al., 1997).

On the hot surface of the TEC module, a large heat sink is used to dissipate the heat that the TEC module has to pump and the internal heat generated by the TEC module itself. This heat is dissipated by the heat sink to the ambient air. The temperature of the heat sink is therefore warmer than the ambient temperature (Slack et al., 1998).

There is three ways of extracting the heat at the hot surface of the TEC module. These include a heat sink with natural convection (no fan), heat sink with forced convection (fan included) and liquid cooling with forced convection. A heat sink with natural convection has a temperature rise of 2°C/W to 0.5°C/W. On the other hand, a heat sink with forced convection has a temperature rise of 0.5°C/W to 0.02°C/W. Liquid cooling has a temperature rise of 0.02°C/W to 0.005°C/W. In order to ensure reliability the hot surface temperature of the TECM must be kept below 85°C (Riffat and Xiaoli et al., 2003).

Thermo Electric refrigerator is designed and simulated to maintain the temperature of enclosure at 4^{o}C. The COP of system will increase with increase of input current . COP is a measure of module performance and it is always desirable to increase or maximize. Selection of the proper thermo electric module for a specific application requires an evaluation of the total system in which the refrigeration will be used. The selection of TEM material is based on nature of cooling (Jyrki tervo et al., 2009).

Summary

In the process of thermo electric refrigeration the cooling effect was effectively used for cooling applications such as storage of medicines, vegetables etc... But heat energy produced by TEC module dissipated to environment. Due to energy crisis, it is important to conserve energy. The heat energy dissipated to environment can be used for heating applications such as hot packs. This technology enables the TEC modules to use both heating and cooling applications at a time and it leads to conservation of energy and recovery of waste heat. In order to conserve conventional electricity, this TER (Thermo-Electric Refrigeration) system is powered by the solar panel arrangements.

3. Methodology

From the cooling load calculations, 105.83 W of load for cooling space and 60.9 W of load for heating spaced required. Depending upon the load, the modules are selected.

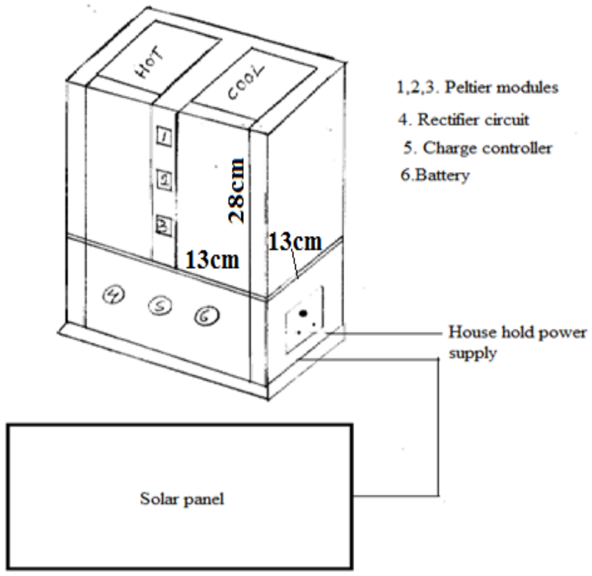

Figure 2: Proposed model design

Load calculations

Specifications of aluminium box
Length = 13cm
Width = 13cm
Height = 28cm
Volume = 13*13*28 = 4732cm^3
Capacity = 4.732 lt
Cooling capacity required = m*c*dt
 = 4.7*4.27*(33-14)
 = 381KJ
 = 105.83W

Module selection

Number of modules required = $\frac{\text{Cooling capacitu required}}{\text{Cooling capacity of module}}$

Cooling capacity of module = 45W

Number of modules required = $\frac{105.38}{45}$ = 2.35

Hence 3 peltier modules are required to obtain the temperature of 14^{o}C inside the cold box. These 3 modules can produce the temperature of 58oC on other side inside the hot box.

4. Experimental Setup

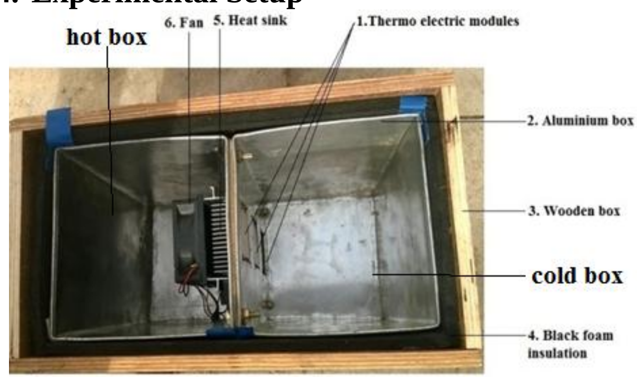

Figure 3: Top view of Thermo Electric Refrigeration system

Figure 4: Fabricated Thermo Electric Refrigerator system powered by solar energy

1. Fabricated Thermo electric heating and cooling system. 2. Solar panel. 3. Power supply from solar panel to battery

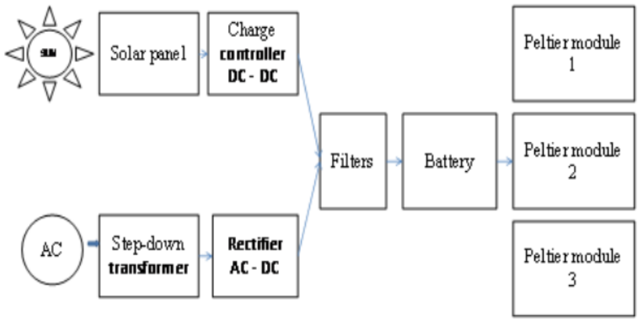

Figure 5: Block diagram

The experimental set up consisting of:

A. Thermo electric modules
B. Solar panel
C. Battery
D. Metal (aluminium boxes)
E. Heat sink with fan
F. Insulation
G. Power supply unit

The main parts of this project are explained below:

A. Thermo Electric modules

For the selected box capacity of 4.7 lit, three Thermo Electric modules are used in the fabrication to obtain 14°C inside the cold box and 58°C inside the hot box. The cooling capacity of one module is 45W. The hot side surface of module is mounting on heat sink. The modules are placed in between the two boxes.

B. Solar panel

Solar pane converts light energy into electrical energy. One square meter of fixed array kept facing south yields nearly 0.5 KWh of electrical energy on a normal sunny day. Here we use a 50 W solar panel with output of 16 V.

C. Battery

Batteries are the devices which stores DC electrical energy in form of chemical energy. In this systems batteries are used for storage of excess solar energy converted into electrical energy. In this fabrication we use a 12 V lead-acid battery.

D. Metal (aluminium boxes)

The aluminium box dimensions used in this project are 13*13*28 cm and the capacity of the box is 4.7 lit. Two aluminium boxes are used, one for cold box and another for hot box.

E. Heat sink with fan

Thermo Electric module hot side surface is mounted on the heat sink to absorb the heat and the fan is used to transfer the heat by forced convection in the hot box.

F. Insulation

A black foam insulation material is used to reduce the heat losses to the surroundings around the two boxes. Cork board insulation is placed in between two boxes to eliminate the heat transfer from hot box to cold box through conduction.

G. Power supply unit

Power supply unit consisting of 230 V AC, 50 Hz house hold supply, step-down transformer and rectifier circuit to charge the battery when solar energy not available.

Assembly Procedure

- First check whether TER module is working or not and find out the cool side and hot side of module by sending DC current through module.
- Apply thermal conductive paste between module hot side and heat sink. A 12 V DC fan connected to heat sink.
- After mounting of module on heat sink, place in between two aluminium boxes such that cold side of module exposed to cold box and heat sink is exposed to hot box.
- Black foam insulation is insulated outside surfaces of boxes to eliminate heat losses to surroundings and cork board insulation placed in between boxes to eliminate heat transfer between boxes.
- The battery is placed under the boxes and circuit connections are given such that battery can supply modules and DC fan. This arrangement is placed inside the wooden box.
- The battery can be charged either by solar panel or house hold supply.

Experimentation

Experiments are conducted to analyse the COP and efficiency. The power supply from the battery which is charged by solar panel is given to system and readings of temperatures at different places inside both boxes are taking by placing the thermo couples near modules, at centre and near corners for every 10 minutes of time. The readings are tabulated and check for least temperatures occur in cold box and maximum temperatures occur in hot box. After that the power is switch OFF and checks for the storage times of the two boxes and readings are taken. The tabulated values are plotted as temperature vs time for power ON and OFF conditions.

5. Results and Discussions

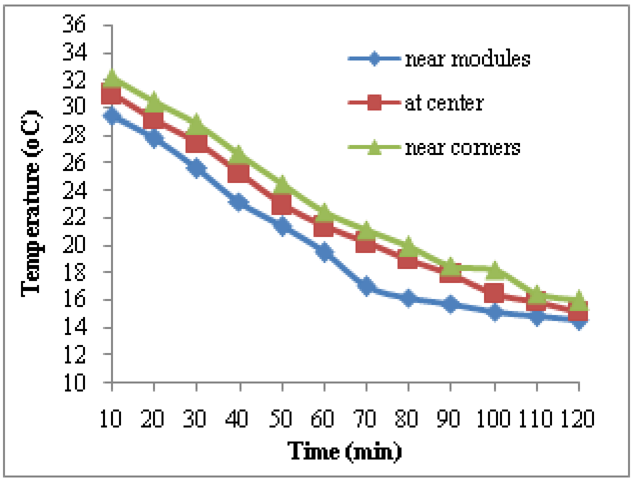

Figure 6: Temperature values inside the cold box (vs) time at power ON condition

The temperature values (^oC) inside the cold box vs the time (min) are plotted as shown in Fig.6 at power ON condition. The temperature readings are taken at different positions inside the cold box at ambient temperature of 34^oC for every 10 minutes up to 120 minutes. The minimum temperature at the centre of the cold box is 14.8^oC.

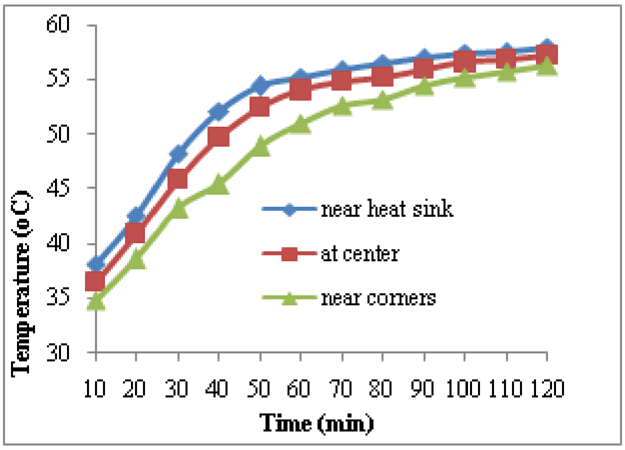

Figure 7: Temperature values inside hot box (vs) time at power ON condition

The temperature values (^oC) inside the hot box vs the time (min) are plotted as shown in Fg.7 at power ON condition. The temperature readings are taken at different positions inside the hot box at ambient temperature of 34^oC for every 10 minutes up to 120 minutes. The maximum temperature at the centre of the hot box is 55^oC.

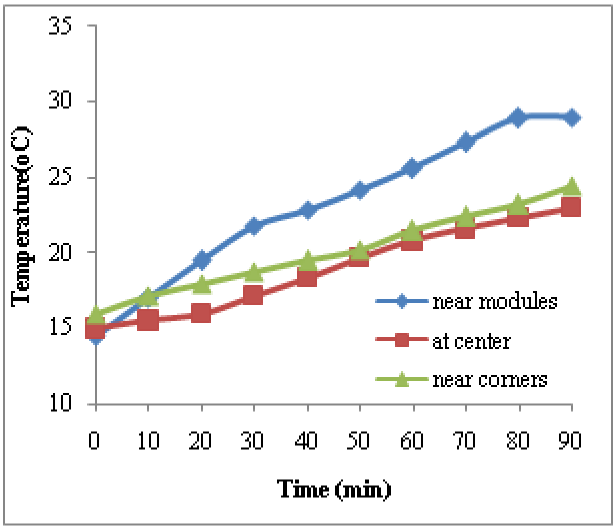

Figure 8: Temperature values inside the cold box (vs) time at power off condition

The temperature values (^oC) inside the cold box vs the time (min) are plotted as shown in Fig.8 at power OFF condition. The temperature readings are taken at different positions inside the cold box at ambient temperature of 34^oC for every 10 minutes up to 90 minutes. Up to 20 minutes we can maintain the same temperature of 14.8^oC at centre of the cold box.

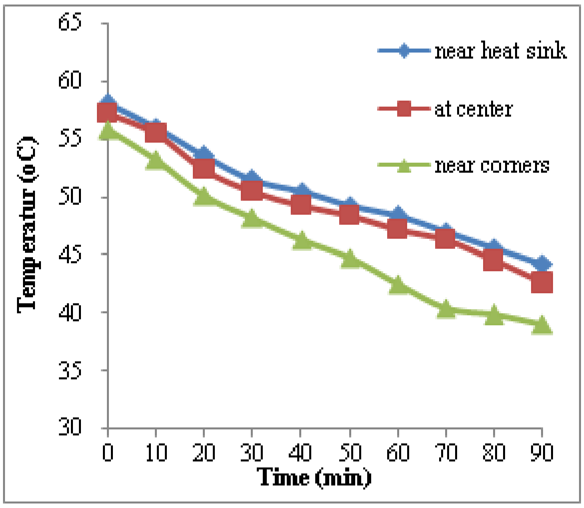

Figure 9: Temperature values inside the hot box (vs) time at power off condition

The temperature values (^oC) inside the hot box vs the time (min) are plotted as shown in Fig.9 at power OFF condition. The temperature readings are taken at different positions inside the hot box at ambient temperature of 34^oC for every 10 minutes up to 90 minutes. Up to 20 minutes we can maintain same temperature of 55^oC at centre of the hot box.

Calculations

Heat absorbed inside the cold side box (Q_{abs}) is the convective heat transfer inside cold box.
Convective heat transfer inside the box (Q_{abs}) = h*A*ΔT
Where h = Free convective heat transfer coefficient of air = 24 W/m^{2}K
A = Area inside the cold box= 0.0406m^2

ΔT= Temperature difference
Input power given (Q_{in}) = 120 W
Heat absorbed inside the cold box (Q_{abs})= 28.53 W
COP (Coefficient Of Performance) = Q_{abs}/Q_{inp} = 0.24
COP of the TER system is 0.24
Heat output in the hot box (Q_{out}) = h*A*ΔT
Where h = Forced convection coefficient of air = 60 W/m^2K
Heat output (Q_{out}) = 60.9 W
Efficiency of the system = Q_{out}/Q_{in}
= 50.75%
The efficiency of the TER system is 50.75%.

6. Conclusion

A portable Thermo Electric system for both cooling and heating applications has been fabricated. The temperature inside the cod box obtained is 14.5°C and the temperature inside the hot box obtained is 58_oC for 2 hours. The COP of TER (Thermo Electric Refrigeration) system is 0.24 and the efficiency of the system is 50.75%. The cooling effect used for storage purpose of materials like medicine, vegetables etc... The heating effect used for heat storage purposes such as hot packs. Hence the fabricated TER (Thermo Electric Refrigeration) powered by solar energy is utilized for both cooling and heating applications.

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Author Profile

P. Amarnath, M.Tech student, ENERGY SYSTEMS, Department of Mechanical Engineering JNTUA Collage of Engineering, Anantapur, Andhrapradesh, India.

Dr. K. Kalyani Radha M.Tech,Ph.D., Assistant Professor, Department of Mechanical Engineering, JNTUA College of Engineering, Ananthapur, Andhrapradesh, India.