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Design and Development of Solar Powered Thermoelectric Refrigeration System for Rural Region

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ABSTRACT

The environmental degradation becomes a great matter of concern due to use and disposal of Chloro-Fluoro-Carbons (CFCs) and Hydro Chloro-Fluoro-Carbons (HCFCs) as refrigerants in conventional refrigeration and air conditioning systems. This leads to extensive research into development of alternate refrigeration systems. Solar energy which is renewable source of energy is available abundantly in the environment. This study deals with the design and development of eco-friendly solar powered thermoelectric refrigeration system. In rural areas where people have to deal with electricity problems, this thermoelectric module will be very helpful to them as it runs on solar energy. Vegetables, Food items and other different required things can be preserved in it. In thermoelectric refrigeration system, the mechanical parts and coolants which are used in conventional refrigeration systems get eliminated and a thermoelectric module is used instead which is cost effective and vibration free. The objective of this study is to develop a working thermoelectric refrigeration system to cool a volume of 5 lit capacity cabinet that utilizes the Peltier effect to cool and maintain a selected temperature range of 8^0C to 15 ^{0}C. Solar panel is used to provide the required energy to run this system.

Keywords : Thermoelectric Effect, Solar Panel, Peltier Effect And Thermoelectric Module

I. INTRODUCTION

Due to the increasing demand for refrigeration in various fields led to production of more electricity and consequently more release of harmful gas like CO_2 all over the world which is a contributing factor of global warming on climate change. Thermoelectric refrigeration is a new alternative method. The thermoelectric modules are made of semiconductor materials electrically connected in series configuration and thermally in parallel to create cold and hot surfaces. Although they are less efficient than the vapour compression system, they are very light, low in cost, silent in operation, and are environmentally friendly.

The conventional cooling systems are used now a days are requires the refrigerant whose phase change takes place in heat exchanging and compressor are required for the compression of the refrigerant. The compressor required more power and space. The refrigerant is also not eco-friendly and increases the global warming and the major cause of ozone layer depletion.

A. The mini Eco-friendly refrigerator is based on the PELTIER EFFECT and a thermoelectric device called Peltier device is used for the cooling purpose. In the MEF-Refrigerator there is no need of compressor and refrigerant. Semiconductor thermoelectric coolers (also known as Peltier coolers) off temperature control (< ± 0.1 °C) can be achieved with Peltier coolers. However, their efficiency is low compared to conventional refrigerators. Thus, they are used in niche applications where their unique advantages outweigh their low efficiency. Although some large-scale applications have been considered (on submarines and surface vessels), Peltier coolers are generally used in applications where small size is needed and the cooling demands are not too great, such as for cooling electronic components.

B. Jonathan Michael Schoenfeld et al [1] in his thesis submitted on integration of a thermoelectric sub cooler in 2008. There are two general research areas focused on increasing TEC performance; materials Research on thermoelectric semiconductors and system level assembly and heat dissipation techniques. The former is focused on developing advanced thermoelectric materials with superior thermoelectric properties. The most important parameter of a thermoelectric semiconductor is the figure of merit, Z, which is given by α2/ (kρe). Each of these properties is temperature dependent so often the of merit will be given at a particular temperature in the dimensionless form, ZT. Increasing the figure of merit directly results in an increase in the optimum COP of a TEC. The most common thermoelectric semiconductor in today's TECs is Bismuth Telluride (Bi_2Te_3), which has a ZT of ~0.9 at 300 K.

C. Bass et al. (2004) [2] investigated the use of multi-layer quantum well (MLQW) thermo electrics in a cooling application. MLQW thermoelectric material is a composite of thin layers of alternating semiconductor material with differing electronic band gaps deposited on a substrate. In this way, the thermal and electrical conductivity of the material can be decoupled. The non-dimensional figure of merit of such composite materials has been determined experimentally to be as high as 3 or 4. Theoretical analysis predicted COPs as high as 5 at a ΔT_m of 20 K. A TEC utilizing MLQW thermoelectric material is still under development. It can be expected that the additional manufacturing costs of such a module would be substantial. Besides the obvious increase in optimum COP provided by such an improvement in thermoelectric properties, it has also been recognized that Tellurium, a main component in Bismuth Telluride, is becoming increasingly rare and expensive, which will eventually lead to a necessary replacement for thermoelectric materials. Further research is still required to develop nanotechnology thermo electrics, with the ultimate hurdle being the fabrication of a scaled up module with an applicable cooling capacity.

D. Chain and Chen et al. (2005) [3] investigated the use of a micro channel heat sink on a TE module used to cool a water tank. The micro channels were etched into a silicon wafer with a glass cover plate. Four micro channel heat exchangers were fabricated with a differing number of ports and hydraulic diameters (D_h), from 89 ports at a D_h of 65 μm to 44 ports at a D_h of 150 μm. Water was pumped at flow rates ranging from 289 – 10,702 ml/h to remove the heat from the hot side of the module. The micro channel was placed on top of a 4 cm x 4 cm TE module. The lowest measured thermal resistance for the heat sink was 1.68 K/W. The authors suggested that the thermal resistance could be reduced to 0.5 K/W by increasing 6 the aspect ratio of the micro channel ports and by using a more conductive material like copper.

E. Webb et al. (1998) [4] investigated the use of a thermo syphon as the heat sink of a TE module used for electronics cooling. A porous aluminium surface was employed to enhance the boiling heat transfer in the evaporator. The condenser was constructed with internal micro fins to enhance condensation. An experimental study was conducted with simulated heat loads typical of a thermoelectric module heat rejection. At 75 W a thermal resistance of 0.0505 K/W was calculated for a 45 mm square enhanced boiling surface. The authors also recognized that the thermal resistance decreased slightly with increasing heat flux. As the figure of merit continues to increase through a continued research effort, the use of thermo electrics for air cooling has become more feasible.

F. Riff at and Qiu et al. (2005) [5] investigated TE air conditioning systems with an air and water cooled heat sink. A cylindrical heat sink was designed through the optimization of the interior fin length and pitch as well as fluid velocity. The cylindrical design was capable of reducing heat exchanger volume and thermal resistance. An evaporative water "condenser" was suggested as the outdoor unit, which would cool the circulated water down close to the wet bulb temperature through convective and evaporative cooling. It was shown that the thermal resistance of a water cooled heat sink was significantly lower than an air cooled heat sink, with values reported as low as 4.75 x 10-4 K/W for a cylinder with an outer surface area of 0.23 m^2. An ideal COP of 1.8 was reported at a ΔT_m of 20 K of merit of Z = 3.0 x 10 -3 K^{-1}. Although possible, it would be difficult to fabricate a TE module on a curved surface as suggested.

G. The objective of this research is to develop portable thermoelectric refrigeration system capable of maintaining the temperatures between 8°C and 15°C. The main system consisted of thermoelectric module as cooling generator along with insulated cabin, battery and charging unit. Thermoelectric elements perform the same cooling function as Freon-based vapour compression or absorption refrigerators. In this project several criteria are considered such as portability, size and cost of the system for design. The design of the preservation is based on the principles of thermoelectric module (i.e. Peltier effect) to create a hot side and a cold side. The cold side of the thermoelectric module is used for refrigeration purposes; provide cooling to the chamber.

II. EXPERIMENTAL SETUP

Thermoelectric refrigeration box is mainly composed of two parts: semiconductor refrigeration system and data acquisition system. The main components of the semiconductor refrigeration system are:

- Solar panel
- Thermoelectric module
- Aluminum Heat sink (Fin)
- DC Fan
- Battery
- Power supply unit
- Cooling Chamber/Insulated box
- Frame

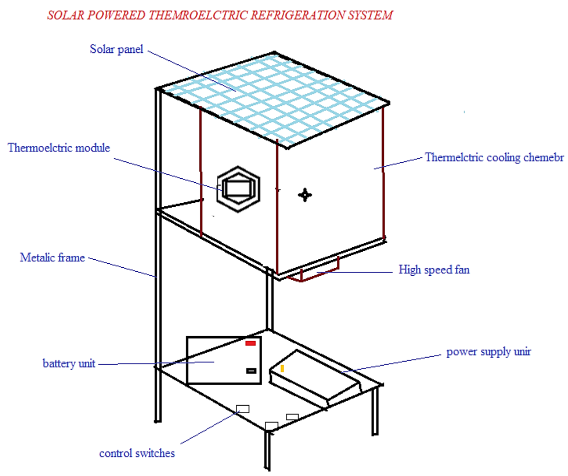

Fig.1. Schematic diagram of the semiconductor refrigeration system

III. THERMAL LOAD CALCULATION

In this experimental model, air-forced convection heat dissipation is employed in heat and cold side. Hot and cold side radiator fins employ aluminium material. Hot and cold side respectively employed two fans to enhance the effect of convection heat transfer. Including both the conductive and convective heat transfer components of the load, the equations are:

$$Q = \frac{\Delta T \ A}{\frac{1}{h} + \frac{L}{k}}$$

Temperature to be maintained inside the cabin = 10 ^{0}C

Outside temperature or ambient temperature = 30 ^{0}C

Temperature difference between the cabinet walls = 30 – 10 = 20 ^{0}C

K_{MS} = 52 W/mK

K_{EPS} = 0.033 W/mK

h_{AIR} = 10 W/m^{2}K

Area of cooling cabinet, $A_1 = A_2 = A_3 = 0.35 \times 0.35 = 0.1225\ m^2$

$$Q = \frac{\Delta T . A}{2 \times \frac{1}{h_{AIR}} + \frac{l_1}{K_{EPS}} + \frac{l_2}{K_{MS}}}$$

$$= \frac{0.1225 \times 20}{2 \times \frac{1}{10} + \frac{0.05}{0.033} + \frac{0.002}{52}} = 1.42\ W$$

Passive load through the walls,

$Q_P = (Q_1 + Q_2 + Q_3) \times 2 = (1.42 + 1.42 + 1.42) \times 2$

$= 8.52\ W \approx 9\ W$

Infiltration air load due to opening and closing, $Q_C \approx 10\ W$

$Q_{TP} = Q_P + Q_C = 9 + 10 = 19\ W$

For analysis, $Q_{TP} \approx 25\ W$

The TEC module was selected by considering few factors such as dimensions, cooling load Q_C, power supply etc. The model number of the module is TEC1-12706. It is decided to select a TEC module which has a cooling power greater than the calculated cooling load. TEC1-12706 operates with an optimum voltage value of 12V. It has a maximum voltage of 15.4V. At 12V it draws and maximum DC current of 6 A. The nominal power rating or the cooling power is 60 W. It has a maximum operating temperature of 200^{0}C. It had been decided to choose 1 TECs of the same model so that when the power of 1 TEC modules are greater than the calculated cooling load. The minimum power rating for 1 TEC modules added together was more than the cooling load calculated. More number of TEC reduces the time required for cooling of a particular material.

The technical parameters are shown in Table 1.

Product	TEC-12706
Operational voltage	12V DC
Current max	6 Amp
Voltage max	15.4 V
Power max	92.4
Power nominal	60
Couples	127
Dimensions	40 x 40 x 3.5 mm

TABLE 1

IV. RESULTS

A. Cooling of water by Convection

Experiments were conducted and note down readings. Graph is drawn between Temperature Vs Time. The insulator (thermocol) was used between metal bowl and surface of cooling chamber. Figure 2 shows temperature decreases from 30°C to 20°C within 90 minutes. The cooling rate of water by convection in cooling chamber (30-20)/90=0.111.

B. Cooling of water by Conduction:

The Figure 3 depicts cooling of water by conduction means there was direct contact between metal bowls containing water and surfaces of the cooling chamber. Graph shows the cooling rate is higher at the starting up

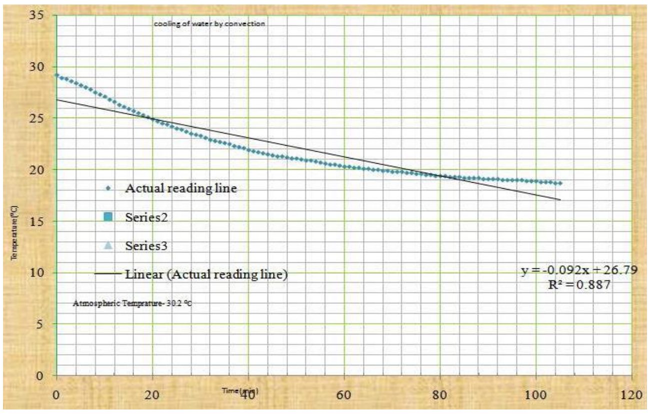

Figure 2. Graphical representation of cooling of water by convection.

to 22°C.Within 90 minutes temp decreases from 30°C to 17°C. The cooling rate of water by conduction is (30-17)/90=0.144 .The cooling rate of water by conduction is higher than the cooling rate of water by convection.

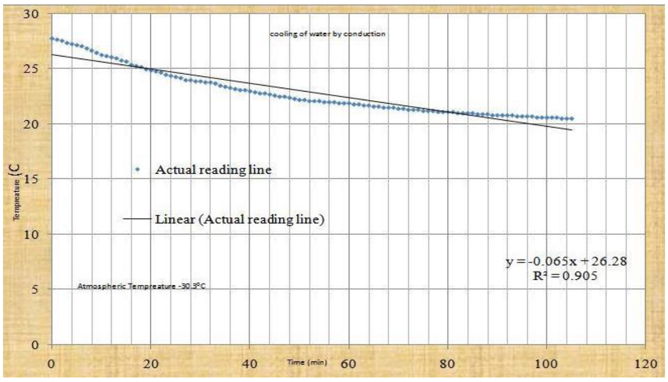

Figure 3. Graphical representation of cooling of water by conduction.

V. CONCLUSION

A solar powered portable 5lit capacity refrigeration system was fabricated using thermoelectric module & electric control unit & tested for the cooling purpose. The study suggests a suitable data required to thermoelectric cooler to determine physical properties and performance of thermoelectric refrigeration system. Present study also develops and optimization design method for thermoelectric refrigerator. Thermo electrical analysis results have indicated that under given condition, there are optimal allocation ratio of the total thermal conductance that can maximize the TEC cooling capacity and COP respectively. 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.

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