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Experimental and mathematical modelling of thermoelectric refrigeration system based on solar energy

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ABSTRACT

Experimental investigation and development of mathematical modeling of thermoelectric refrigeration system running on solar energy is carried out. In this system thermoelectric cooling module (Peltier module) is selected based on design parameters. Conventional refrigeration systems are bulky that leads to disadvantages like environmental issues, moving parts etc. whereas in thermoelectric refrigeration system all mechanical parts replaced by thermoelectric module. A thermoelectric module works on Peltier effect to create a hot side and cold side. The cold side of thermoelectric module is used in refrigerator space for cooling purpose and hot side is used to reject heat to the atmosphere by using heat sink. The experimental setup was developed having capacity 0.5 liter for the investigation using two numbers of Peltier modules (TEC 1-12706). The fins were designed for the heat sink fan assembly in order to increase heat dissipation rate from hot side of Peltier module. Experiments were conducted on developed prototype to analyze parameters: current, temperature difference, time and coefficient of performance (COP) and it is found that temperature reduction of 24^{o}C in 7 minutes with reference to ambient temperature and COP about 0.35 to 0.69. The mathematical model is developed for validation of obtained results.

Keywords— **Solar energy, Peltier module, Thermoelectric refrigeration (TER), Coefficient of performance (COP).**

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I. INTRODUCTION

With the increase awareness towards environmental degradation due to the production, use and disposal of Chloro Fluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) as heat carrier fluids in conventional refrigeration and air conditioning systems. Thermoelectric refrigeration is new option because it can convert waste electricity into useful cooling, is expected to play an important role in today's energy challenges. It does not require working fluids or any moving parts, which is friendly to the environment and it simply uses electrons rather than refrigerants as a heat carrier. Continuous efforts are given by researchers for development of thermo electric materials with increase figure of merit may provide a potential commercial use of thermoelectric refrigeration system. Author concentrates on development of renewable energy (solar) based TER system and its performance evaluation along with mathematical modelling. Efforts can be made to increase the COP of the system by increasing the rate of convectional heat transfer and selection of thermoelectric module with higher figure of merits.

II. LITERATUREREVIEW

Recently, the global increasing demand for refrigeration, e.g. air-conditioning, vaccine storages, food preservation, medical services, and cooling of electronic devices, led to production of more electricity and consequently more release of CO_2 all over the world [1] which it is contributing factor of global warming on climate change. TER is new alternative because it can convert waste electricity into useful cooling, is expected to play an important role in today’s energy challenges [2].

Dai et al. [3] developed a thermoelectric refrigeration system powered by solar cells and carried out experimental investigation and analysis. Researchers developed a prototype which consists of a thermoelectric module, array of solar cell, controller, storage battery and rectifier. The studied refrigerator can maintain the temperature in refrigerated space at 5–10oC, and has a COP about 0.3

under given conditions. Wahab et al. [4] have designed and developed an affordable solar thermoelectric refrigerator for the desert people living in Oman where electricity is not available. In this study, they used 10 nos. of thermoelectric module in design of refrigerator. The experimental results indicated that the temperature of the refrigeration was reduced from 27 to 5 oC in approximately 44 min. The coefficient of performance of the refrigerator was calculated and found to be about 0.16 . Abdullah et al. [5] have carried out an experimental study on cooling performance of a developed hybrid Solar Thermoelectric-Adsorption cooling system. The developed system produced cooling via the Peltier effect during the day, by means of thermoelectric elements, and through adsorption (activated carbon-methanol) process at night. They evaluate the coefficient of performance by using derived equations, the average COP values of the hybrid cooling system were found about 0.152 for thermoelectric system and about 0.131 for adsorption. Francis et al. [6] evaluated the performance of thermoelectric refrigerator. The research focused on simulation of a thermoelectric refrigerator maintained at 4oC. The performance of the refrigerator was simulated using Matlab under varying operating conditions. The system consisted of the refrigeration chamber, thermoelectric modules, heat source and heat sink. Results show that the coefficient of performance (C.O.P) which is a criterion of performance of such device is a function of the temperature between the source and sink. For maximum efficiency the temperature difference is to be kept to the barest minimum.

III. WORKING PRINCIPLE OF TER

Solar energy is applied to power input to the thermoelectric module. The cold side of the thermoelectric module is utilized for refrigeration purposes. On the other hand, the heat from the hot side of the module is rejected to ambient surroundings by using heat sinks and fans.

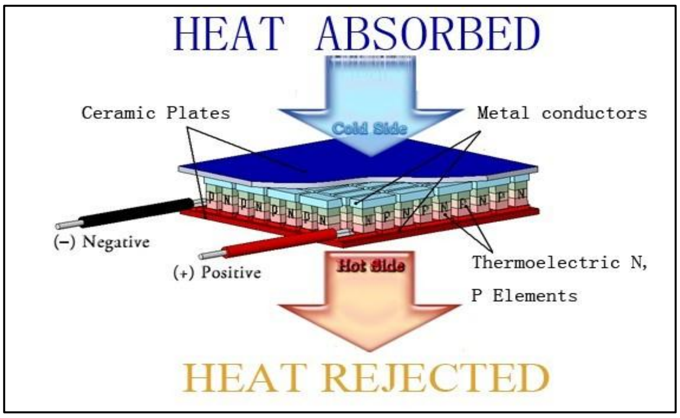


Fig. No.1 working principle of TE module

Thermoelectric coolers operate by the Peltier effect. The device has two sides, and when DC current flows through the device, it brings heat from one side to the other, so that one side gets cooler while the other gets hotter. The "hot" side is attached to a heat sink so that it remains at ambient temperature, while the cool side goes below room temperature. In some applications, multiple coolers can be cascaded together for lower temperature.

IV. DESIGN ANALYSIS

Design and develop an experimental thermoelectric refrigeration system with a refrigeration space of 0.5Liter capacity with outer casing of MS sheet and for thermal insulation a Glass wool sheet has been provided inside the box to prevent reversal of heat flow. A thin aluminium sheet (0.4mm) box has been fixed inside the MS box for uniform distribution of temperature.

Two numbers of thermoelectric modules (TEC1-12706) have been used to reduce inside temperature of refrigeration space. Cold side of TEM mounted on Aluminum sheet and hot side of modules were fixed with heat sink fan assembly. Two numbers of fin heat sink fan assembly (MODEL NO. – REC 9225 A 12 MW) were used for each module to enhance the heat dissipation rate.

System design calculations:

- Desired temperature of cold compartment: $8^\circ C$
- Ambient temperature : $32^\circ C$
- Mass of water to be cooled : 0.5 Kg

Using Newton's law of cooling:

$Q_c = m\,Cp \times (Ta - Tc)$

$= 0.5 \times 4180(32 - 8)$

$Q_c = 50232$ J

$Q_c = 50232 / (7 \times 60)$

$Q_c = 119.6$ watt

Dimensions of cabinet is 10cm x10cm x 15cm And thermal conductivity of Aluminum is 167 W/M k, To find hot side temperature of TE Modules, T_h; keeping heat sink at $15^\circ C$ above ambient temperature:

$T_h = T_{amb} + 15^\circ C = 32 + 15 = 47^\circ C$

Now, temperature difference ΔT across the TE module can be calculated as follows,

$\Delta T = (T_h - Tc) = 47 - 8 = 39^\circ C$

So, $39^\circ C$ will be used for design calculations parameters to be used for TE module selection,

$Q = 60$ W, $\Delta T = 39^\circ C$

TABLE I
SPECIFICATION OF TE MODULE

Type	I_{max} (A)	V_{max} (v)	Q_{max} (w)	ΔT (^0C)	R (ohms)
TEC1-12706	6.4	14.4	60	39	1.98

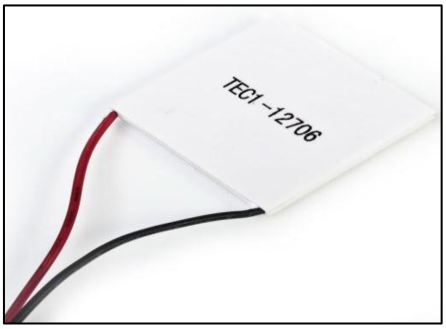


Fig. No. 2 Peltier module

Thermal resistance e of heat sink,

$$R_{hs} = \frac{T_h - T_a}{VI + Q_{Tec}}$$

R_{hs} = 0.049 K/W

A heat sink of rating 0.049 k/w or less must be use with each TEC module.

TABLE III
SPECIFICATION OF HEAT SINK FAN

Model	Voltage (V)	Current (I)	Input power (W)	Speed (rpm)	Air flow (CFM)
9225 A12MW	12	0.14	1.68	2600	46

Selection of solar panel first we have to need calculation of total load:-

In solar panel two loads are act is given below

Total power consume by module-

= 60 per module × (use two modules)
= 60 × 2= 120 watt

Power required to drive fan=1.68 × Two fans = **3.36 watt**

Total power / load on the system = Total power consume by module + Power required to drive a fan

Total power load on the system = 120 watt + 3.36 watt

Total power /load on the system = **123.36 watt**

To design a solar panel at **123.36 watt**

1 cell produces 1.8 watt power

Hence no. of cell required = total load on the system/1.8
= 123.36/1.8

No. of cell required = **68 cell**

125 W solar panel as per standard

Fig. No. 3 Experimental setup of system

A DC power supply system was developed to power the developed thermoelectric refrigeration. This system consist two nos. of solar PV panel fixed on a frame with provision of angle variation for optimum solar radiation incidence on PV panel.

Selection of the battery at following consideration-

Now we want to set up a solar system for 2 Peltier module and 2 fans (12 Volt DC),

Hence total load on the system-

Two Peltier module = 2 × 60 = 120 watt

Two heat sink fan = 2 × 1.68 = 3.36 watt

Total load on the system = 120 + 3.36 watt
= 123.36 watt

Now we want to five hours battery backup time

Then total load on the battery = 71.96 watt × 5 hour
= 359.8 watt per hr

To measure the battery ampere for the above load.

Voltage = 12 volt

$I = \frac{359.8}{12}$

I = 29.98 =30 amp hr.

Battery is needed 12 volt, 30 AH.

To select a battery in 12 volt 35 amp

Solar charge controller specification is as follows-(as reference to solar panel specification at 12 volt, 6.4 amp)

a. Rated charge current = 6 amp
b. Rated load current = 6 amp
c. Maximum solar input voltage = 20 volt
d. Rated working voltage = 12 volt DC

At above specification solar charge controller is selected

Testing the performance of the thermoelectric refrigeration:

When designed prototype was tested, it was found that the inner temperature of the refrigeration area was reduced from 320C to 80C in approximately 7minutes, i.e. 240C. Following example shows how the coefficient of performance was calculated. It was assumed that the refrigerator used to cool a 0.5 L from 320C to 80C in 7 Min.

Calculate COP;

COP = Qc / Win

Where, Qc=119.6 W
Win = VI = 14.4 X 6.4

V. Result and Discussion

First experiments were conducted for performance evolution of above specified two thermoelectric cooling modules. The performance of TEM was evoluted at variable input electrical current conditions. In this section, we are discusses the analysis of thermoelectric refrigeration system by varying the various parameters like current and time.

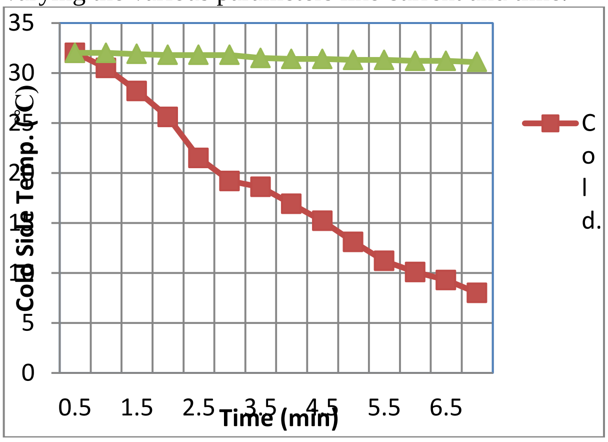
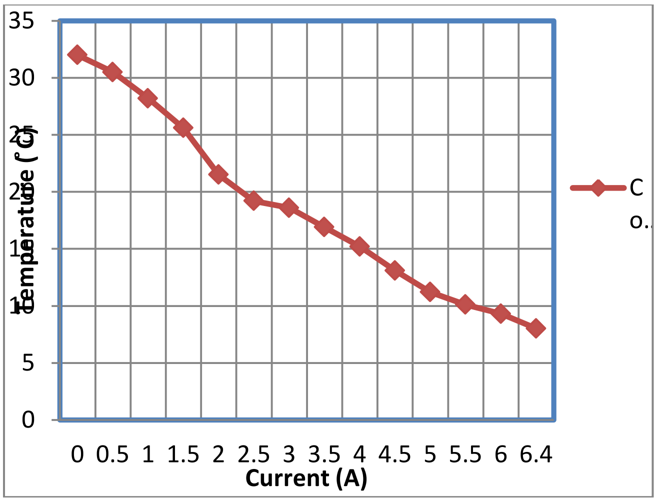


Fig.No. 5 Relaionship between temprature of sides of thermoelectric module & time



The experimental results figure (5) shows that variation cold side temperature with respect to time. It shows that change in cold side temperature decreases with time exponentially.
The experimental results figure (6) shows that variation cold side temperature with respect to current. It shows that change in cold side temperature decreases with time exponentially. Also fig. No. 7 shows the relation between COP & Current.

VI.Conclusion

Present study developes a design of thermoelectric cooler (Peltier module) and suggest a suitable data required to

Win = 92.16 W
Win = 92.16 X 2 (no. of module) = 184.32 J

COP = 119.6 / 184.32

COP = 0.648

thermoelectric cooler also determine physical properties and performance of thermoelectric refrigeration system. Present study also developes and optimization design method for thermoelectric refrigerator. The proposed simple model in used in the optimization of real 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 that TEC cooling capacity and COP respectively. The energy efficiency of thermoelectric refrigerators, based on currently available materials and technology, is still lower than its compressor counterparts. However, a marketable thermoelectric refrigerator can be made with an acceptable COP.
Further improvement in the COP may be possible through improving module contact resistance, thermal interfaces and heat exchanger. With its environmental benefit, thermoelectric refrigerator provides an alternative to consumer who is environmentally conscious and willing to spend a little bit more money to enjoy their quiet operation, and more precise and stable temperature control.

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