Design and Development of Thermoelectric Refrigerator

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Abstract - *The global increasing demand for refrigeration in field of refrigeration air-conditioning, food preservation, vaccine storages, medical services, and cooling of electronic devices, led to production of more electricity and consequently more release of CO_2 all over the world which it is contributing factor of global warming on climate change. Thermoelectric refrigeration is new alternative because it can convert waste electricity into useful cooling, is expected to play an important role in meeting today's energy challenges. Therefore, thermoelectric refrigeration is greatly needed, particularly for developing countries where long life and low maintenance are needed. The objectives of this study is design and develop a working thermoelectric refrigerator interior cooling volume of 18L that utilizes the Peltier effect to refrigerate and maintain a temperature from 33 °C to 22 °C. The design requirements are to cool this volume to temperature within a time period of 1 hr and to obtain COP in the range of 0.2 to 0.6. The design requirement, options available and the final design of thermoelectric refrigerator for application are presented.*

Key Words**: Carbon dioxide, thermoelectric refrigerator, interior cooling volume, time period, COP etc.**

1. INTRODUCTION

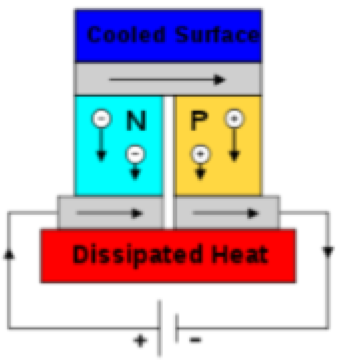
Refrigeration means removal of heat from a substance or space in order to bring it to a temperature lower than those of the natural surroundings. Thermoelectric cooling is a way to remove thermal energy from a medium, device or component by applying a voltage of constant polarity to a junction between dissimilar electrical conductors or semiconductors. Thermoelectric Refrigeration provides cooling effect by using thermoelectric effect i.e. Peltier effect rather than the more prevalent conventional methods like those using the 'vapor compression cycle' or the 'gas compression cycle'.

Thermoelectric Refrigeration finds applications in electronic systems and computers to cool sensitive components such as power amplifiers and microprocessors. TER can also be used in a satellite or space application to control the extreme temperatures that occur in components on the sunlit side and to warm the components on the dark side. In scientific applications like digital cameras and charge-coupled devices (CCDs) TER are used to minimize thermal noise, thereby optimizing the sensitivity and image contrast.

The coefficient of performance (COP) of compression refrigerators decreases with the decrease in its capacity. Therefore, when it is necessary to design a low capacity refrigerator, TER is always preferable. Also, better control over the space temperature is the major advantage of the TER. Hence, TER is good option for food preservation applications & cooling of pharmaceutical products.

1.1 PRINCIPLE

Peltier Effect: It states that when electric current is maintained in a circuit of material consisting of two dissimilar conductors, one junction becomes cold and the another junction becomes hot.



1.2 MATERIAL REVIEW

Thermoelectric module is made of two different semiconducting materials, which generate thermoelectric cooling effect (Peltier effect) when a voltage of similar polarity & in appropriate direction applied through the connected junction. Two heat sinks & fans are attached to hot and cold sides of thermoelectric module in order to enhance heat transfer and system performance. There exists an optimum current & optimum voltage for maximum coefficient of performance (COP) for a specific module and fixed hot/cold side temperatures.

According to the primary criterion of figure of merit;

$$\left(Z = \frac{\alpha^2}{RK}\right).$$

a good thermoelectric material should have high Seebeck coefficient, high electrical conductivity, and low thermal conductivity. Commonly used thermoelectric materials are Bismuth Telluride (Bi_2Te_3), Lead Telluride (PbTe), Silicon Germanium (SiGe) and Cobalt Antimony ($CoSb_3$), among which $Bi2Te_3$ is the most commonly used one. These materials usually process a ZT value (figure of merit at temperature) less than one. From 1960s to 1990s, developments in materials in the view of increasing ZT value was modest, but after the mid-1990s, by using nano structural engineering thermoelectric material efficiency is greatly improved. Thermoelectric materials such as primary bulk thermoelectric materials like skutterudites, clathrates and half-Heusler alloys, which are principally produced through doping method are developed but not exploited for commercial use. [10]

The best commercial thermoelectric materials currently have ZT values around 1.0. The highest ZT value in research is about 3. Other best reported thermoelectric materials have figure-of-merit values of 1.2-2.2 at temperature range of 320-520^{0}C. It is estimated that thermoelectric coolers with ZT value of 1.0 operate at only 10% of Carnot efficiency. Some 30% of Carnot efficiency could be reached by a device with a ZT value of 4. However, increasing ZT to 4 has remained a formidable challenge. Bell also mentioned that if the average ZT reaches 2, domestic and commercial solid-state heating, ventilating and air-cooling systems using thermoelectric material would become practical. [10]

2. LITERATURE REVIEW

Jincan Chena et al.,[1]:- According to non-equilibrium thermodynamics ,cycle models of single-stage and two-stage semiconductor thermoelectric refrigeration were experimentally investigated. By using the three important parameters which governs performance of thermoelectric refrigerator i.e. coefficient of performance (COP), the rate of refrigeration, and the power input, development of general expressions performances of the two-stage thermoelectric refrigeration system took placed. It was concluded that performance of thermoelectric refrigerator depends on temperature ratio of heat sink to cooled space. When this ratio is small, the maximum value of COP of a two-stage thermoelectric refrigeration system is larger than COP of a single-stage thermoelectric refrigeration system; however maximum rate of refrigeration is smaller than that of a single-stage thermoelectric refrigeration system. Hence it is convenient to use single stage thermoelectric refrigerator when ratio is small. When temperature ratio is large two stage thermoelectric refrigerator is observed to be superior than single stage by both parameters i.e. maximum value of COP and maximum rate of refrigeration.

X.C. Xuan et al., [2]:- In this paper Two stage thermoelectric refrigerator was investigated with two design configurations. Two configurations were pyramid style and cuboid style as shown in respective figures. In pyramid style configuration top side is being coldest as current is unidirectional. In cuboid style configuration current can be alternated causing top and bottom side to be switched between heating and cooling mode. To obtain optimization methods other multi stage designs can be used. The point of maximum cooling capacity and maximum COP both were taken into consideration while investigation for optimization for the two-stage TE coolers. It was concluded that value lies between 2.5-3 for both parameters that is optimum limit of ratio of number of thermo electric modules of two stages in pyramid style TE cooler and optimum limit of ratio of electric current between stages of cuboid style TE cooler. Maximum temperature difference of pyramid-style cooler is greater than single stage cooler.

Jun Luo et al., [3]:- Using finite time Thermodynamics theory performance of a thermoelectric refrigeration system, with multielements was analysed. To improve and maximise the cooling load and coefficient of performance (COP) optimisation of the ratio of the heat transfer surface area of the high temperature side to the total heat transfer surface area of the heat exchangers was done. The analysis of number of parameters which affects optimum performance of Thermoelectric system was done , parameters were number of thermoelectric refrigerating elements, the Seeback coefficients, internal heat conductance, the heat source temperature and internal electrical resistance. As well as the analysis of other parameters like influences of total heat transfer surface area and working electrical current on the optimum performance was done. They concluded that the cooling load and coefficient of performance (COP) of TE system is greatly influenced by total heat transfer surface area and working electrical current. These results can be used for designing and manufacturing of practical Thermoelectric refrigerators.

D. Astrain et al.,[4]:- In this paper a device using phase change material based on Thermosyphon principle was developed. This device was used and tested as a heat dissipater for hot side of TE cooler. Performance of TE cooler with this device was compared with TE cooler with conventional heat dissipater made up of fins. It was concluded that with the help of developed phase changing device it is possible to reduce thermal resistance between hot side of TE cooler and atmosphere up to 23.8% at 293 K ambient temperature and 51.4% at 308 K ambient temperature, compared to commercial finned heat sink . Decrease in thermal resistance ultimately causes heat to dissipate more effectively from heat sink of TE cooler, therefore improving the COP of TE cooler. At the same values of temperatures it was observed that COP increases by 26% and 35% respectively.

Yuzhuo Pan, et al, [5]:- Author of this paper designed and analyzed an Irreversible multi-couple thermoelectric refrigerator, which operates between two reservoirs maintained at constant temperature. Effect of other factors like external and internal irreversibility of thermoelectric refrigerator on performance was also studied. They have specified many important parameters which affects coefficient of performance (COP) of system. Results of obtained from experiments leads to knowledge of information about performance characteristics of real multi-couple thermoelectric refrigerator. This information may be used to manufacture and design thermoelectric refrigerator which will perform at its optimum level.

Hongxia Xi.et al, [6]:- In this paper Author done survey on solar based driven Thermo electric technology. A brief history of development of solar based driven Thermo electric technology was presented. It's today's status and drawbacks present in current Technologies were reviewed. Applications, future scope, advantages over conventional technology where also discussed. In this paper they have discussed about two main modes, that are solar based thermoelectric power generation and refrigeration. Current status of both Technologies was described. Problems related to this technology and there possible solutions were presented. Ultimately these Technologies with some more development may lead to solve demand of Environment protection and energy conservation.

Suwit Jugsujinda et al, [7]:- In this paper they have fabricated thermoelectric refrigerator using thermoelectric cooler. Thermoelectric refrigerator (25 × 25 × 35 cm^3) and thermoelectric cooler (4 × 4 cm^2). This system was applied to 40 W electric power without any cooling fan as heat dissipater at heat sink. They have measured temperature of this system at ten different points. It was concluded that these experiments results into temperature of cold side of thermoelectric cooler to be decreased from 30°C to -4.2°C for 1 hour and decreased to -7.4°C for 24 hours with heat plate temperature being 50 °C. Temperature of cold side of thermoelectric refrigerator decreased from 30°C to 20°C for 1 hour and decreased further in 24 hours. 3 and 2.5 are the maximum value of coefficient of performance (COP) of thermoelectric cooler and thermoelectric refrigerator respectively.

S.A.Omer et al, [8]:- This paper presents some results of thermoelectric refrigeration system using phase change materials (PCM) integrated with thermosyphones. They investigated two models of thermoelectric refrigeration system, one with conventional finned devices as heat dissipater and other with phase change material (PCM) as heat dissipater. After results they have concluded that coefficient of performance (COP) and effectiveness of thermoelectric refrigeration system with Phase Change Material (PCM) is higher than conventional one. They have also compared thermoelectric refrigeration system of two kinds, one is using phase change materials (PCM) without thermal diode and other integrated with thermal diode (Thermosyphones). Results shows that thermosyphones used prevent leakage of heat during power off. Overall they have concluded system can be work with the help of renewable energies like solar energy producing electricity. It is suited for medicine and food storage.

3. CONSTRUCTION

The cabin of volume 21 lit. is fabricated using galvanized sheets and polyurethane foam(puff). The inner surface of the cabin is insulated completely using puff (3.8mm) so as to isolate the cooling cabin from the atmosphere. The thermoelectric module is sandwiched between two CPU heat sinks of different sizes using thermal paste to set a single unit. Thermal paste plays a vital role in conduction of heat from Peltier module to the aluminum heat sinks. One such unit is made.

These units are placed in the cut slots with the smaller CPU heat sink facing the interior of the cooling cabin and the larger CPU heat sink on the outside of the cabin to establish greater heat rejection. Additionally fans are fitted on the inner and outer side of the heat sinks. Electrical connections are made and power is supplied from a 12V battery eliminator. K type thermocouples are placed inside the cabin and outside the heat sink to record the temperatures. Separate control panel containing dc eliminator switches and temperature indicator is made for taking readings.

4. WORKING

Experiments are conducted to analyses the COP. The power supply from the battery eliminator is given to system and readings of temperatures at different places are taken by placing the thermocouples near modules, at center and outside the heat sink for every 10 minutes of time. The readings are tabulated and check for least temperatures occur in cabin and maximum temperatures occur at the outside heat sink. After that the power is switch OFF and checks for the storage times of the cabin and readings are taken. The tabulated values are plotted as temperature vs time for power ON and OFF conditions.

5. EXPERIMENTAL SETUP

Fig.1 Fabricated setup of thermoelectric refrigerator

6. CALCULATIONS

Coefficient of Performance (COP):- To evaluate the efficiency of refrigeration cycles, a dimensionless parameter called COP is used. In refrigeration systems, COP is defined as the ratio of useful cooling provided to work required.

$$\mathrm{COP} = \frac{Q_c}{W}$$

In the below equations, αm, Km, Rm are the device Seebeck voltage, device thermal conductance and device electrical resistance.

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

$$= \frac{14.4}{307}$$

$$= 0.04691/K$$

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

$$= \frac{(307-66)\times 14.4}{307\times 6.4}$$

$$= 1.7662\ \Omega$$

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

$$= \frac{(307-66)}{2\times 66} \times \frac{14.4\times 6.4}{307}$$

$$= 0.548\ /K$$

$$Q_C = (\alpha_m \times I \times T_c) - (\frac{I^2}{2} \times R_m) - (K_m \times (T_h - T_c))$$

$$= (0.04691\times 6.4\times 286) - (\frac{6.4^2}{2} \times 1.7662)$$

$$- (0.548\times(307-286))$$

$$= 38.1843 \text{ Watts}$$

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

$$= 0.04691\times 6.4\times(307-286) + (6.4^2\times 1.7662)$$

$$= 78.6482 \text{ Watts}$$

1. Theoretical COP:

$$(COP)_{Theoretical} = \frac{Q_c}{W}$$

$$= \frac{38.1843}{78.6482}$$

$$= 0.4855$$

2. Actual COP:

$$\text{Mass of air } (m) = \rho \times V$$

$$= 1.225\times 0.01880$$

$$= 0.02303 \text{ Kg}$$

$$\text{Refrigeration Effect (RE)} = \frac{mC_p\Delta T}{t}$$

$$= \frac{0.02303\times 1.005\times 10^3\times(44-22)}{60\times 60}$$

$$= 0.1414 \text{ Watts}$$

$$(COP)_{Actual} = \frac{RE}{W}$$

$$= \frac{0.1414}{0.45}$$

$$= 0.3142$$

7. RESULT AND DISCUSSION

Table.1: Result

Sr. No.	Parameter	Values
1	Maximum temperature difference in ºC	22
2	Time taken in minutes	60
3	$(COP)_{theoretical}$	0.4855
4	$(COP)_{actual}$	0.3143

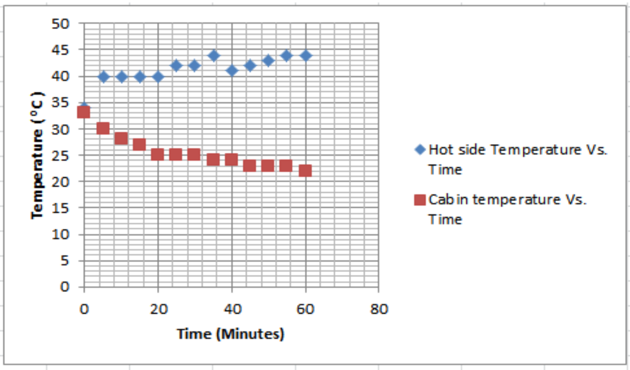


Fig.8.3 Temperature(°C) vs Time(min.)

From result table and graphs, it can be concluded that as time goes on increasing, the temperture inside the cabin falls down gradually. At the same time, hot side temperature remains constant (near about 40°C).

8. CONCLUSIONS

1. The Coefficient of performance of the system for TEC1-12706 is calculated from the average of readings. It is observed that COP of Thermoelectric refrigeration using TEC1-12706 is lesser than COP of VCRS.
2. Solar power can be used as power source to the system as it is a renewable source of energy. This immensely decreases the working cost of the refrigerator and burden on the earth.
3. Liquid cooling at hot side can be used to increase the refrigeration effect.
4. Waste heat can be recovered using ducts for heating purpose,

5. Number of Peltier modules or multistage Peltier modules can be used to increase the cooling effect.

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