Design and Experimentation of Thermoelectric Refrigerator for Cold Storage Application

Vivek Vaidya[1], Prajwal Manwatkar[2], Mehul Narnaware[3], Utkarsh Gadve[4], Samule Anvikar[5]

[1]Assistant Professor, Department of Mechanical Engineering, K.D.K. College of Engineering, Nagpur

[2, 3, 4, 5]Students, Department of Mechanical Engineering, K.D.K. College of Engineering, Nagpur

Abstract: ***In recent years, with the increase awareness towards environmental degradation due to the production, use and discharge of Chloro Fluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) as heat carrier fluids in conventional refrigeration systems has become a subject of great concern and resulted in extensive research into development of refrigeration technologies. Thermoelectric operated cooler provides a best alternative in refrigeration technology due to their distinct advantages. While using thermoelectric effect in system the Coefficient of Performance (COP) of the system also increases. In this paper we proposed method to increases COP of thermoelectric refrigerator and also conducting research for development of renewable energy based TER system. The TER system have been designed and developed an experimental thermoelectric refrigeration system having refrigeration space 5 lit is cooling by eight module and heat sink fan assembly for thermoelectric module to increases heat dissipation rate .The calculated COP of thermoelectric refrigeration cabinet was 0.16 with an average indoor temperature of 30^0C***

Keywords: Thermoelectric module, Hydro Chlorofluorocarbons (HCFCs), Coefficient of Performance (COP)

1. Introduction

Refrigeration can be defined as the process of extracting heat from a substance using a heat exchanger. Space cooling is the same phenomenon as refrigeration, though heat is extracted from a defined space, to ensure that the temperature in the space is maintained lower than the surroundings. Refrigeration has been required since early times. Food materials, start decomposing at higher temperatures. Preservation of food caused the commercial usage of a refrigerator. Refrigeration has been used commercially since 1900s. Traditional refrigeration and space cooling techniques have made use of the Refrigerator, Air Cooler or Air Conditioner. The major components of a traditional refrigeration system are compressor, condenser, and evaporator and throttle valve. Major drawback of these systems is that they consume large amount of electricity, are expensive and not feasible for use where electricity is not dependable. This has led to consideration of alternatives to space cooling and refrigeration. There is a huge market and demand for thermoelectric cooling, except for a few drawbacks which can be easily overcome with serious consideration. A thermoelectric module belongs to the family of semiconductors that acts as a heat pump. It works on Peltier effect to produce the required output.

In 1834, a French watchmaker and part time physicist, Jean Peltier found that an electrical current would produce a temperature gradient at the junction of two dissimilar metals . The Peltier effect is the main contributor to all thermoelectric cooling applications. It is responsible for heat removal and heat absorbance. 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.

$$Q \alpha I$$
$$Q = \pi ab I$$
$$\pi ab = \pi a - \pi b$$

where (πa & πb) is the Peltier coefficient of conductor A & B, and I is the electric current (from A to B).

Min et al. developed a number of prototype thermoelectric domestic-refrigerators with different heat exchanger combination and evaluated their cooling performances in terms of the COP, heat pumping capacity, cooling down rate and temperature stability. The COP of a thermoelectric refrigerator is found to be 0.3-0.5 for a typical operating temperature of 5 oC with ambient at 25°C. Lertsatitthanakorn et evaluated the cooling performance and thermal comfort of a thermoelectric ceiling cooling panel (TE-CCP) system composed of 36 TEM. The standard was met with the TE-CCP system operating at 1 A of current flow with a corresponding cooling capacity of 201.6 W, which gives the COP of 0.82 with an average indoor temperature of 27°C. Gillott et al. conducted an experimental investigation of thermoelectric cooling devices for small-scale space conditioning applications in buildings. They performed a theoretical study to find the optimum operating conditions, which were then applied in the laboratory testing work. A TEC unit was assembled and tested under laboratory conditions. Eight pieces of Ultra TEC were shown to generate up to 220W of cooling effect with a COP of 0.46 under the input current of 4.8A for each module.

In this paper, we have fabricated a prototype of thermoelectric refrigerator for cold storage of food and medicines and carried out its experimental investigation for the analysis of system performance.

2. Experimental Set Up and Test Procedure

In this proposed work, the main aim is to develop a refrigeration system with a capacity of 5L of cooling chamber. It is necessary to design a system capable of maintaining the temperature of the materials between 5 ^{0}C to 15 ^{0}C for a long duration. Moreover the system is meant for outdoor use which makes better insulation and radiation control mandatory. In order to meet worse scenario, even though the system is to designed for maintaining a fixed chamber temperature throughout the operational period, the design should be such that it can adaptable for refrigerating the chamber from ambient temperature to the required temperature.

2.1 Materials Used in Refrigeration System

In this proposed work, to develop a refrigeration system we used some materials, which are as follows:

2.1.1 Cabinet

With the constraints imposed by the objectives a double walled rectangular box with an insulation sandwiched between the walls is selected and having the following dimensions

Top and bottom panel dimensions = 0.25 x 0.25m
Vertical side panel dimension = 0.25 x 0.25m
Front and back panel dimensions = 0.25 x 0.25 m

2.1.2 Insulation Material

Mild steel sheets with thermal conductivity of 52W/mK were used as outer wall. Expanded polystyrene (EPS) slabs with 5cm thickness having a density of 30kg/m^3 and thermal conductivity of 0.033W/mK were used to give the required thermal insulation

2.1.3 Thermoelectric Cooling Modules

The thermoelectric module consists of thermocouple formed by pairs of P-type and N-type semi-conductor thermo element which are electrically connected in series configuration and thermally connected in parallel configuration. Due to their solid state construction the modules are considered to be highly reliable. For most application they will provide long, trouble free service. For cooling application, an electrical current supply is given to the module, heat is transferred from one side to the other, and the result is that the module will become cooler at one side and hotter at the other side.

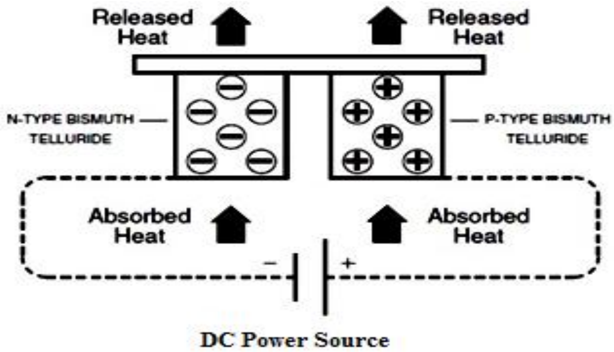

Figure 1: Module working

The Figure 1 shows the working of thermoelectric module. When a DC voltage is applied to the TE module, the positive and negative charge carriers in the pellet assemblage absorb heat energy from one of the surface and reject it to the other at the opposite side. The surface area where heat energy is absorbed gets cooler; the opposite surface where heat energy is released gets hotter. Reversing the polarity will result in reversed hot and cold sides.

3. Design Work Module

We designed and developed an experimental thermoelectric refrigerator (Figure 2) with refrigeration space of 5Liter capacity. Eight numbers of Super cool make thermoelectric cooling modules (Imax=4.7A, Vmax= 12V) (Figure 2) were selected on the basis of active heat and passive heat removal from thermoelectric refrigeration cabinet.

Figure 2: Schematic Diagram of developed thermoelectric refrigeration cabinet

Active heat load is the heat dissipated by the mass being cooled and calculated by using equation (1).The passive heat load is the heat loss due to convection & conduction of enclosed thermoelectric cabinet and calculated by using equation (2).

$$Q_{active} = \frac{mCp\Delta T}{dt} \quad (1)$$

$$Q_{passive} = \frac{A\Delta T}{\left\{\frac{X}{k}+\frac{1}{h}\right\}} \quad (2)$$

Cold side of TEM mounted on refrigeration cabinet and hot side of module was fixed with heat sink. A black anodized heat sink fan assembly (Figure 2) with thermal resistance of 0.50^{o}C/W has been used for each module to enhance the heat removal rate. The heat sink has been selected on the basis of experimentally evaluated thermal resistance. The thermal resistance has been calculated as.

$$R_h = \frac{T_h - T_a}{Q_h}$$

$$Q_h = Q_a + Q_p + Q_{TEM}$$

4. Experimental and Performance Analysis

An experimental and performance analysis on fabricated thermo electric refrigerator was conducted. The cold end of the thermoelectric module was used in the system to cool the refrigerator cabin and a digital thermo meter is used to measure the temperature. The hot end is attached to a heat sink for heat rejection. In order to validate the performance of the system cool down experiment was conducted on the system.

4.1 Cool down test

For analyzing the performance of system, water load is considered as the active heat load to the system. Water at 33˚C was filled in the container before switching ON the system. The temperature at every 20min.intervel was tabulated. The readings were recorded for 450mins.

Table 1: Variation of temperature with time

Sr. No.	Time	Temperature
1	0 min (Initial)	33 ^{0}C
2	50 min	28.6^{0}C
3	100 min	25.2^{0}C
4	150 min	23.8^{0}C
5	200 min	22.1^{0}C
6	250 min	20.3^{0}C
7	300 min	18.7^{0}C
8	350 min	16.9^{0}C
9	400 min	14.6^{0}C
10	450 min	13.2^{0}C

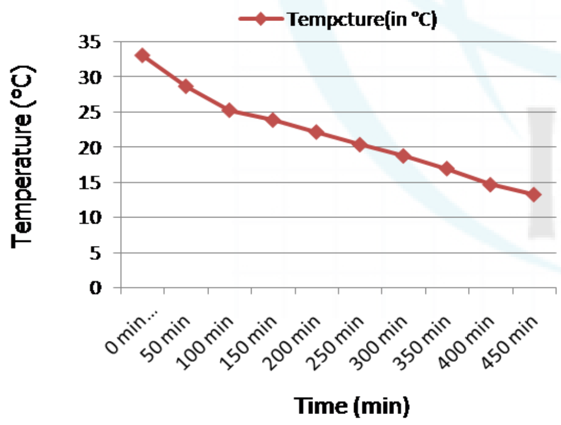

Figure 3: Variation of temperature with time

Even though the conventional system is mainly designed for maintain a fixed temperature, the above cool down experiment was proved that the system can be adapted for sensible cooling also. The figure 3 shows the variation of temperature with time in the given setup. The lower steady temperature was attained around 13.2°C at a time of 450 minutes.

4.2 Performance of the Thermoelectric Refrigerator

The active heat load is expressed as the equivalent cooling power that the unit will need to provide when the sample at ambient temperature is placed in the container. It was decided that two litter of water at room temperature took as the test sample .When the designed thermoelectric refrigerator was tested, it was found that the inner temperature of the refrigeration area was reduced from 33 ˚C to 13.2 ˚C in approximately 450min. Coefficient of performance of the refrigerator (COP_R) was calculated. Water is used in place of vaccine for taking measurements and calculation. In these calculations, the properties of water are (density = 1 kg/L and C_P = 4187 J/kg).V=2L.

Temperature to be maintained inside the cabin = 7 ^{0}C
Outside temperature or ambient temperature = 30 ^{0}C
Temperature difference between the cabin walls=30–7=23^{0}C
Coefficient of performance of the refrigerator (COP_R) was calculated,

$$COP = \frac{Q_{cooling}}{W_{in}}$$

$$Q = mC_p\Delta T$$

Mass of water, m = density x volume = 2 kg
Total heat removed from the water = 185902.8 J

$$Q_{colling} = \frac{Q}{\Delta T}$$

$$= \frac{185902.8}{450\times 60}$$

= 6.88 W.

Power given to the system for working,
W_{IN} = V x I + fan input
= 4.7 *12+ 2
= 58.4 W

Coefficient of performance of this refrigeration system is

$$COP = \frac{6.88}{58.4}$$

$$= 0.16$$

COP of this refrigerator system is lower than conventional refrigerator. This is because the efficiency of thermoelectric modules is usually four times lesser than that of vapour compression system. And the heat leakage is also detected through doors; this too reduces the efficiency of the system.

5. Conclusion

In this paper we have been successfully design and developed Thermoelectric Refrigeration system that fulfils the proposed goals. However we do realize the limitations of this system. The present design can be used only for light heat load to lower its temperature to a particular temperature. The system is unable to handle fluctuations in load. Extensive modifications need to be incorporated before it can be released for efficient field use. This is one of the advantageous project which uses low power to drive refrigerator.

References

[1] Chetan Jangonda , Ketan Patil , Avinash Kinikar , Raviraj Bhokare , M.D.Gavali5 " *Review of Various Application of Thermoelectric Module*", International

Journal of Environmental Science and Development, Vol. 5, Issue 3, March 2016.

[2] Manoj B. Dhawade, Ekta Mourya, Anurag Yadav, David Samuel, Suprabhat A. Mohod5, Vaibhav N Deshpande **6**, "*Review On Portable Solar Thermoelectric refrigerator Cum Air Cooler*", International Journal of Environmental Science and Development, vol. 88, pp. 182-191, 2013.

[3] Mr. Swapnil B. Patond, Miss. Priti G. Bhadake, Mr. Chetan B. Patond, " *Experimental Analysis of Solar Operated Thermo-Electric Heating and Cooling System* ", International Journal of Engineering Trends and Technology (IJETT) – Volume 20 Number 3 – Feb 2015

[4] S. C. Kaushik, Solar Refrigeration and Space conditioning, Jodpur: Divyajyoti Prakasan, 1989.

[5] S. C. Kaushik, Ranjana Hans, and S. Manikandan, "Theoretical and Experimental Investigations on Solar Photovoltaic Driven Thermoelectric Cooler System for Cold Storage Application", International Journal of Environmental Science and Development, Vol. 7, No. 8, August 2016

[6] Manoj Kumar Rawat1, Himadri Chattopadhyay2, Subhasis Neogi, "a review on developments of thermoelectricrefrigeration and air conditioning systems: a novel potential green refrigeration and air conditioning technology", International Journal of Environmental Science and Development, Vol. 3, No.3, August 2013

[7] Gao Min and Rowe D.M., 2006, "Experimental evaluation of prototype thermoelectric domestic-refrigerators", Applied Energy, 83 (2): 133-152.

[8] Gillott Mark, Liben Jiang and Saffa Riffat, 2010, "An investigation of thermoelectric cooling devices for small-scale space conditioning applications in buildings", International Journal of Energy Research, 34: 776–786.

[9] Lertsatitthanakorn C., Lamul Wiset, and S. Atthajariyakul, 2009, "Evaluation of the Thermal Comfort of a Thermoelectric Ceiling Cooling Panel (TE-CCP"), System Journal of Electronic Materials, 38: (7) 1472-1477.