

Study, Analysis and Fabrication of Thermoelectric Cooling System

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ABSTRACT - In present scenario, with the increase in awareness towards environmental degradation due to the production, use and disposal of Chloro-Fluoro-Carbons (CFCs) and Hydro Chloro-Fluoro-Carbons (HCFCs) as refrigerants in conventional refrigeration and air conditioning systems has become a subject of great concern and resulted in extensive research into development of alternate refrigeration systems. Thermoelectric cooling provides a promising alternative technology due to its distinct advantages. A thermoelectric refrigerator is a refrigerator that uses the Peltier effect to create a heat flux between the junctions of two different types of materials. TEC also called as Peltier cooler is a solid state heat pump which transfers heat from one side of the device to the other side against the temperature gradient (from cold to hot), with consumption of electrical energy. Design and developmental methodology of thermoelectric refrigeration has been presented in detail. The developed thermoelectric refrigeration system is having potential application of storage and transportation of life saving drugs and biological materials at remote areas of our country where grid power is unavailable.

Index Terms – Peltier effect, thermo electric cooling, alternate refrigeration, portable cooler.

I. INTRODUCTION

In 1821, Thomas Seebeck discovered that a continuously flowing current is created when two wires of different materials are joined together and heated at one end. This idea is known as the Seebeck Effect.

The Peltier effect was discovered in 1834 by a French physicist Jean Charles Peltier. Peltier found that the application of a current at an interface between two dissimilar materials results in the absorption/release of heat. They use no ozone depleting chlorofluorocarbons, potentially offering a more environmentally responsible alternative to conventional refrigeration. They can be extremely compact than compressor-based systems. According to Nolas et al [1], from the middle 1950s to the present the major thermoelectric material design approach was that introduced by A.V. Ioffe, leading to semi-conducting compounds such as Bi₂Te₃ (Bismuth telluride), which is currently used in thermoelectric refrigerators. Seebeck effect and Peltier effect forms the basis for the thermoelectric refrigerator.

Scottish scientist William Thomson (later Lord Kelvin) discovered in 1854 that if a temperature difference exists between any two points of a current carrying conductor, heat is either evolved or absorbed depending upon the material.

The Peltier effect is one of three types of thermoelectric effect.

II. STUDY

Thermo electric module

The thermoelectric module consists of pairs of P-type and N-type semi-conductor thermo element forming thermocouple which are connected electrically in series and thermally in parallel. A standard module consists of thermocouples connected in series and sandwiched between two ceramic plates. By applying a current to the module one ceramic plate is heated while the other is cooled. The direction of the current determines which plate is cooled. The number and size of the thermocouples as well as the materials used in the manufacturing determine the cooling capacity. Cooling capacity varies from fractions of Watts up to many hundreds. Different types of TEC modules are single stage, two stage, three stage, four stage, centre hole modules etc.

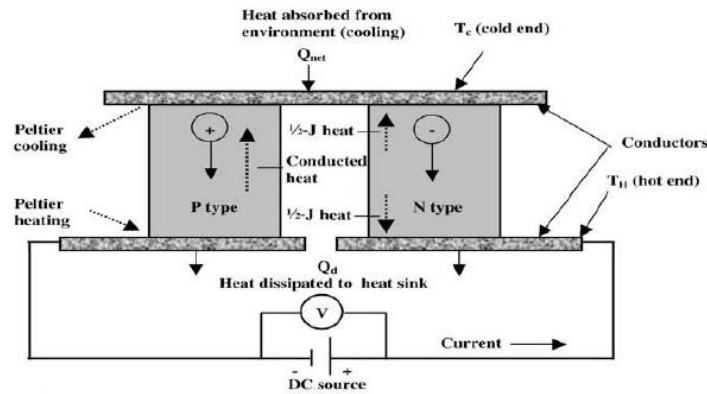


Figure 1. Schematic of thermo electric module operation – Cooling mode.

Heat sink

The heat sink made of aluminium, is in contact with the hot side of a thermoelectric module. When the positive and negative module leads are connected to the respective positive and negative terminals of a Direct Current (D.C) power source, heat will be rejected by the modules hot side, the heat sink expedites the removal of heat. Heat sink typically is intermediates stages in the heat removal process whereby heat flows into a heat sink and then is transferred to an external medium. Common heat sinks include free convection, forced convection and fluid cooled, depending on the size of the refrigerator.

Cold side temperature

If the object to be cooled is in direct contact with the cold surface of the thermo electric module, the required temperature can be considered the temperature of the cold side of thermo electric module (T_c). Here in this project the object is air inside the cabin, which has to be cooled when passed through a cluster of two aluminium CPU heat sinks. The aim is to cool the air flowing through the CPU heat sinks. When this type of system is employed the cold side temperature of the thermo electric module is needed to be several times colder than the ultimate desired temperature of the air.

Hot side temperature

The hot side temperature (T_h) is mainly based on the two factors. First parameter is the temperature of the ambient air in environment to which the heat is been rejected. Second factor is the efficiency of the heat sink that is between the hot side of thermo electric module and the ambient air.

Temperature difference

The two temperatures T_c and T_h and the difference between them ΔT is a very important factor. ΔT has to be accurately determined if the cooling system is expected to be operating as desired. The following equation shows the actual ΔT.

$$\Delta T = T_h - T_c$$

Actual ΔT is not same as the system ΔT. Actual ΔT is the difference between the hot and cold side of the thermo electric module. On the other hand system ΔT is the temperature difference between the ambient temperature and temperature of the load to be cooled.

Cooling Load

The most difficult and important factor to be accurately calculated for a TEC is the amount of heat to be removed or absorbed (Q_c) by the cold side of the TEC. In this project Q_c was calculated by finding the product of mass flow rate of air, specific heat of air and temperature difference. Here the temperature difference system ΔT in the difference between the inlet temperature and outlet temperature of the cooling system. The mathematical equation for Q_c is as shown below.

$$Q_c = m.C_p.\Delta T$$

III. ANALYSIS

Geometric Characteristics

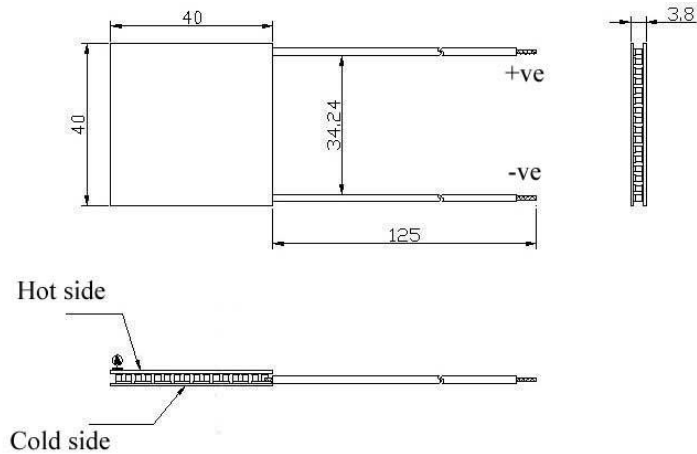


Figure 2. Geometric Characteristics of Peltier module TEC1-12706 (Dimensions in mm)

Naming of the module

The Peltier module used in this project is TEC1-12706.

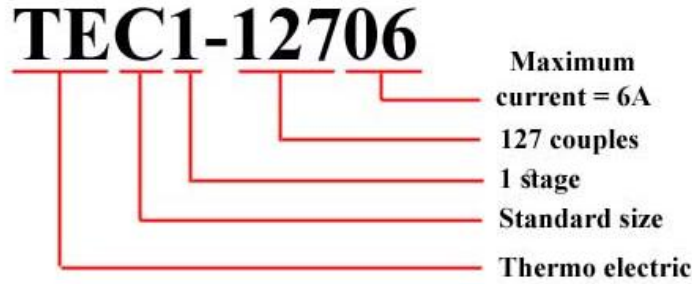


Figure 3. Naming of the module.

Performance curves at $T_h = 27\text{ }^\circ\text{C}$ [6]

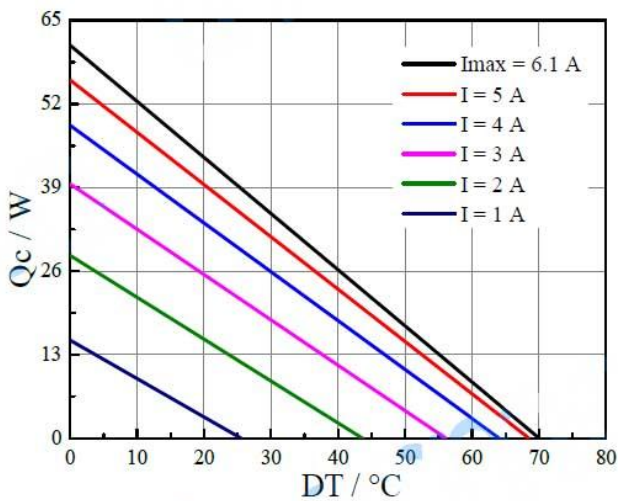


Figure 4. Standard performance graph $Q_c = f(DT)$

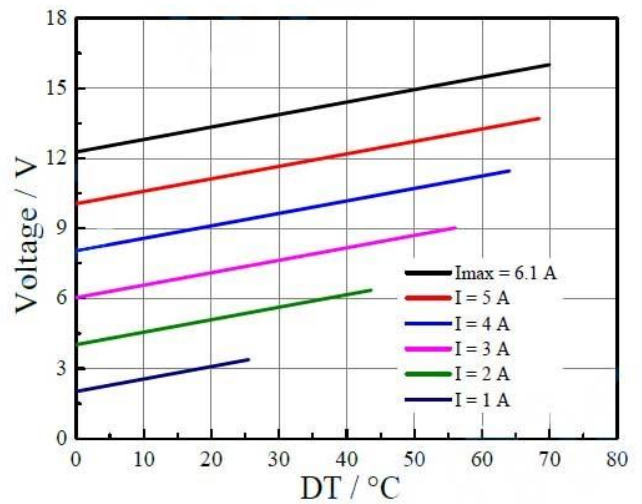


Figure 5. Standard performance graph $V = f(DT)$

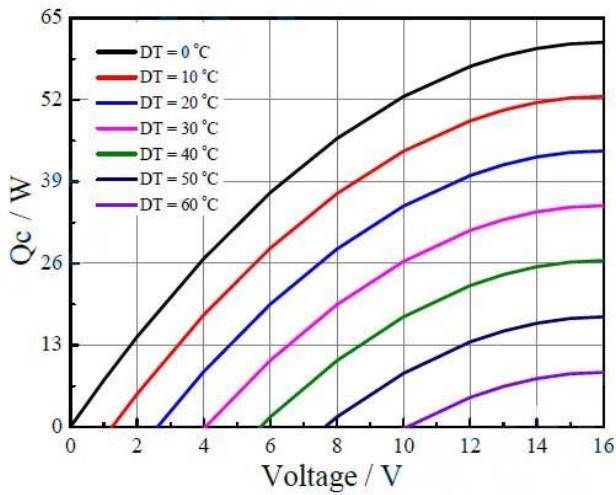


Figure 6. Standard performance graph $Q_c = f(V)$

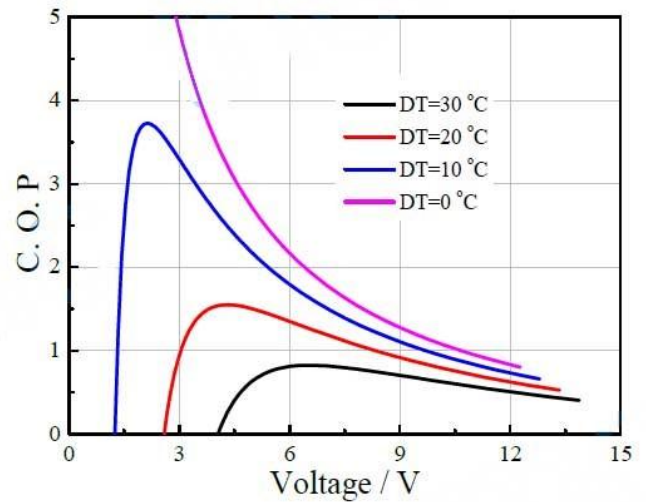


Figure 7. Standard performance graph $COP = f(V)$

IV. FABRICATION

Components used in fabrication of this project are:

- Peltier Module.
- CPU Heat Sinks.
- Cooling fans.
- 12V DC battery.
- Aluminium sheet.
- Connecting wires.
- Thermocol box.
- Thermo paste.

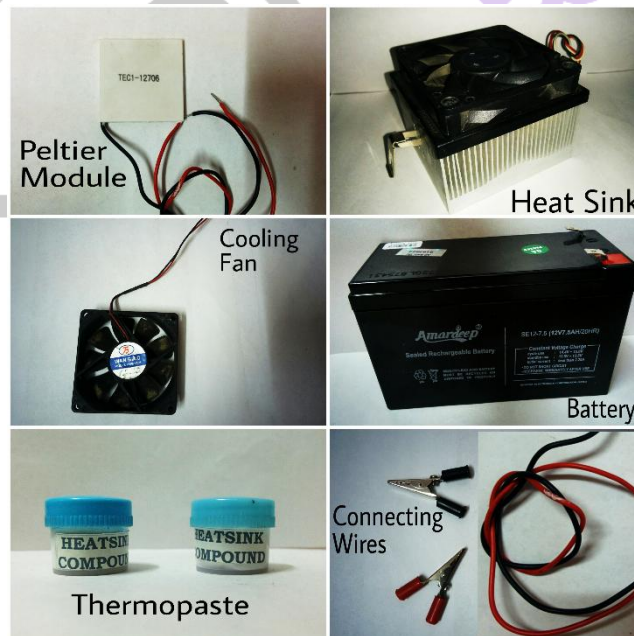


Figure 8. Components used in fabrication

Fabrication Procedure

- A thermocol box of inner cabin volume of 1 ft³ is slotted on 2 opposite faces with the reference of the measurement of CPU heat sinks (50mmx60mm).
- The inner surface of the cabin is insulated completely using aluminium sheets (0.1mm) so as to isolate the cooling cabin from the atmosphere.
- The thermo electric module is sandwiched between two CPU heat sinks of different sizes using thermo paste to set a single unit. Thermo paste plays a vital role in conduction of heat from Peltier module to the aluminium heat sinks. Two such units are made.

- These units are placed in the cut slots with the smaller CPU heat sinks facing the interior of the cooling cabin and the larger CPU heat sinks on the outside of the cabin to establish greater heat rejection.
- Additionally SMPS fans are fitted on the outer side of the heat sinks.
- Electrical connections are made and power is supplied from a 12V dc battery.

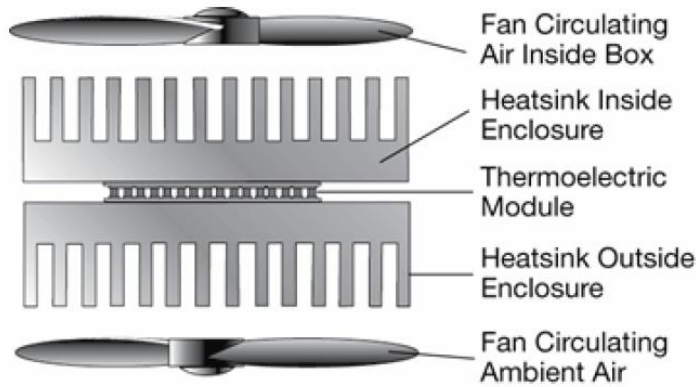


Figure 9. Arrangement of Peltier module, heat sinks and fans.

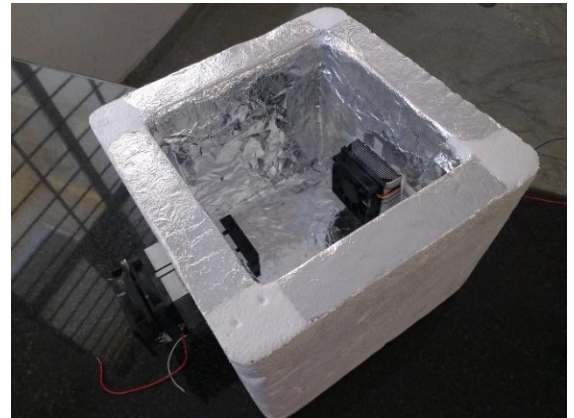


Figure 10. Thermo electric cooling system.

V. CALCULATIONS

For the Peltier module used (TEC1-12706), [2]

- $T_h = 298 \text{ K}$
- $T_c = 283 \text{ K}$
- $Q_{c \text{ max}} = 50 \text{ W}$
- $\Delta T_{\text{max}} = 66 \text{ K}$
- $I_{\text{max}} = 6.4 \text{ A}$
- $V_{\text{max}} = 14.4 \text{ V}$

Where, T_h and T_c are the temperatures at hot and cold side of the module respectively. $Q_{c \text{ max}}$ is the cooling capacity at cold side of the module when $\Delta T = 0$. ΔT_{max} is the maximum possible temperature difference between the cold and hot side of the module when $Q_c = 0$. I_{max} is the maximum input current at $Q_c = 0$. V_{max} is maximum DC voltage at $Q_c = 0$.

In the below equations, α_m , K_m , R_m are the device Seebeck voltage, device thermal conductance and device electrical resistance under the assumption of all identical couple and the unidirectional heat flow.

$$\alpha_m = \frac{V_{\text{max}}}{T_h} = \frac{14.4}{298} = 0.04832 \text{ /}^\circ\text{K}$$

$$R_m = \frac{T_h - \Delta T_{\text{max}}}{T_h} \times \frac{V_{\text{max}}}{I_{\text{max}}} = \frac{298 - 66}{298} \times \frac{14.4}{6.4} = 1.7516 \text{ } \Omega$$

$$K_m = \frac{T_h - \Delta T_{\text{max}}}{2\Delta T_{\text{max}}} \times \frac{V_{\text{max}} \times I_{\text{max}}}{T_h} = \frac{298 - 66}{2 \times 66} \times \frac{14.4 \times 6.4}{298} = 0.5435 \text{ /}^\circ\text{K}$$

$$\begin{aligned}
 Q_c &= (\alpha_m \times T_c \times I) - \left(\frac{I^2 R_m}{2} \right) - (K_m (T_h - T_c)) \\
 &= (0.04832 \times 283 \times 6.4) - \left(\frac{6.4^2 \times 1.7516}{2} \right) - (0.5435 (298 - 283)) \\
 &= 43.1151 \text{ W}
 \end{aligned}$$

$$\begin{aligned}
 W &= \alpha_m \times I \times (T_h - T_c) \times I^2 R_m \\
 &= 0.04832 \times 6.4 \times (298 - 283) + (6.4^2 \times 1.7516) \\
 &= 76.9981 \text{ W}
 \end{aligned}$$

Theoretical COP

$$\begin{aligned}
 COP &= \frac{Q_c}{W} \\
 &= \frac{43.1151}{76.9981} \\
 &= 0.56
 \end{aligned}$$

Actual COP

$$RE = \frac{m C_p \Delta T}{t}$$

Here,
 $m = 250 \text{ ml of water} = 0.00025 \text{ m}^3$
 $C_p = 4.187 \text{ KJ/Kg}$
 $\Delta T = (26 - 16)^\circ\text{C} = 10^\circ\text{C}$
 $t = 15 \text{ minutes}$

$$\begin{aligned}
 RE &= \frac{0.25 \times 4.187 \times 10}{15 \times 60} \\
 &= 0.01163 \text{ KW}
 \end{aligned}$$

$$\begin{aligned}
 COP &= \frac{RE}{W} \\
 &= \frac{0.01163 \times 1000}{76.3448} \\
 &= 0.15
 \end{aligned}$$

VI. FURTHER IMPROVEMENT

This system can be further improved by installing thermo sensor which can be programmed using arduino board, to vary the power supply within specified range of temperature.

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.

VII. ADVANTAGES

- No refrigerants are used, hence this has no effect on ODP and GWP.
- Initial set up cost is low compared other type of refrigeration systems.
- The usage of electric power is less.
- Compact, hence portable.

VIII. APPLICATIONS

The developed thermoelectric refrigeration system is having potential application of storage and transportation of life saving drugs and biological materials at remote areas of our country where grid power is unavailable.

IX. CONCLUSION

Thermoelectric refrigerators are greatly needed, particularly for developing countries, where long life, low maintenance and clean environment are needed. In this aspect thermoelectrics cannot be challenged in spite of the fact that it has some disadvantages like low coefficient of performance and high cost. These contentious issues are the frontal factors hampering the large scale commercialization of thermoelectric cooling devices.

The solution to above problems can only be resolved with the development of new techniques. There is a lot of scope for developing materials specifically suited for TE cooling purpose and these can greatly improve the COP of these devices. Development of new methods to improve efficiency catering to changes in the basic design of the thermoelectric set up like better heat transfer, miniaturization etc. can give very effective enhancement in the overall performance of thermoelectric refrigerators.

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