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# Cost-effective Refrigerator Using Thermoelectric Effect and Phase Change Materials

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**Abstract**— Refrigeration, by definition, is the process of lowering the temperature of an item below what it would have normally been by storing it in a system that is designed to cool or freeze its contents. Contemprary refrigerators that utilize compressor based cooling fail to retain their efficiency when their capacity is reduced. In this context, our project aims at providing an alternate, more efficient, means of cooling by making use of the Thermoelectric Effect as opposed to the conventional methods that are prevalent today.

**Index Terms**— Refrigerator, Thermoelectric cooling. Peltier Effect, Phase Change Materials, Economical, Heat sink, Insulation, Environmentally friendly.

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## 1 Introduction

THE conversion of temperature difference into electric voltage and vice-versa is known as the thermoelectric effect. A thermoelectric device is one that generates a voltage difference across a junction when there are different temperatures on either side and, conversely, creates such a temperature difference when a voltage is applied across it. Three main separately identified effects are encompassed by the term "thermoelectric effect", they are: The Seebeck effect, Thomson effect and Peltier effect.

The Peltier effect is the heat transfer that takes place at the junction of two dissimilar electrified semi-conductors. When current is passed through a thermocouple, heat is absorbed at one junction and is released at the other. Hence, by making use of the cold junction of a peltier plate, refrigeration can be effectively provided to compact chambers.

In our project, we aim to further increase the efficiency of the thermoelectric system by using phase change materials (PCMs). PCMs are materials with large energy densities that allow heat transfer to take place at a constant temperature. A PCM is characterized by the fact that the heat absorbed by it is used to change its phase rather than its temperature. By selecting a suitable PCM, the temperature difference across the peltier plate can be maintained at a low value, greatly increasing its performance.

## 2 Construction

Thermoelectric (TE) Refrigerators are based on the basic laws of thermodynamics and semiconductor technology. When designing a TE refrigerator it is of paramount importance to have a thorough understanding of these concepts to ensure optimal performance. In this section, we discuss the major components of our cooler and the thought process behind their construction.

### 2.1 The Thermoelectric Cooler

Thermoelectric couples are made by combining two different conductors at their extremeties. When a current is made to flow through the thermocouple, heat is absorbed at the cold junction and released at the hot junction [3]. The amount of heat absorbed or generated depends on the magnitude of the current and the number of linkages within the thermocouple. Several such couples are linked together in the making of a thermoelectric cooler.

Choosing the correct material for the thermoelectric couple is important and although metals might seem to be a good choice at first, their low electrical resistance is counter productive and lowers the overall DT (difference in temperature across the TE couple). For this reason, semiconductors are the material of choice.

Bismuth Telluride ($Bi_2Te_3$) is the most commonly used semiconductor in the thermoelectric coolers of today. It is highly anisotropic and hence its electric resistance is much greater parallel to the axis of crystal growth than perpendicular to it. Hence, when the thermoelectric cooler is designed, the cooling module must be designed in such a way that the crystal growth axis lies parallel to each element. This ensures that the anisotropy of Bismuth Telluride is optimally harnessed.

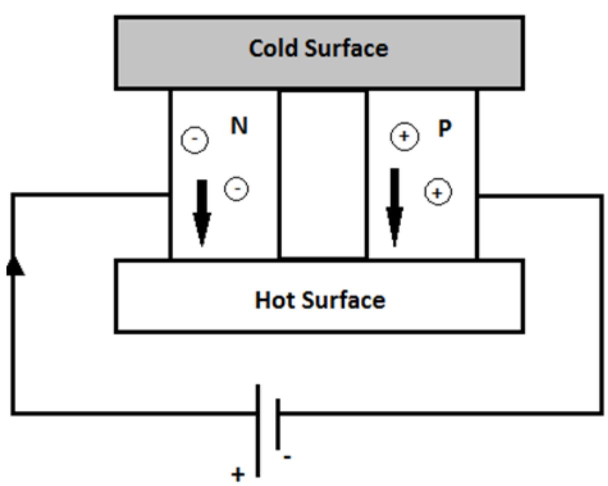


Fig. 1. Schematic diagram to show the working of a thermoelectric cooler.

### 2.2 The Heat-Sink

Heat sinks are *passive* heat exchangers. Their function is to cool a device or volume by dissipating heat into the surroundings. In refrigerators they are used to remove heat from the cooing compartment. Factors such as air velocity, material choice,

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protrusion design etc. affect the performance of a heat sink and must be looked into individually [1].

Heat sinks are usually made of metal, which serve as thermal conductors and carry heat away from the required area and towards the surroundings. Metals with high values of thermal conductivity are preferred as they are more efficient at transferring heat.

Aliminium is the most commonly used metal in heat sinks since it is cheap, lightweight and has a relatively high thermal conductivity (235 watts per Kelvin-meter). Copper, which has a very high thermal conductivity of almost 400 W/mK, is used to make heat sinks in situations that require extensive heat dissipation.

Table 1 shows the thermal conductivities of various metals that are suitable contendors to be used as heat sinks.

TABLE 1
THERMAL CONDUCTIVITY OF IMPORTANT METALS

| Material | Thermal Conductivity (W/mK) |
|---|---|
| Aluminium | 220 |
| Copper | 388 |
| Beryllium | 175 |
| Iron | 71 |
| Tin | 64 |
| Gold | 318 |
| Silver | 418 |



### 2.3 Insulation

The purpose of a thermal insulator is to retard the transfer of heat. In a refrigerator, the insulator prevents outside heat from entering the cooling chamber, which has been cooled to the required temperature.

A good insulator reflects all the heat that is incident on it and does not emit any of its own. Refrigerators utilize several types of insulators, such as vacuum, polyurethane or certain types of Styrofoam.

Heat transfer occurs in three basic ways: Conduction, convection and radiation. Convection works on the principle of gas molecules transferring heat energy to other gas molecules by bulk movement. Vacuums do not contain any gases and thus using a vacuum practically eliminates the transfer of heat due to convection. A **vacuum insulated panel** (VIP) is one type of thermal insulation which is based on this concept. It uses a gas-tight enclosure surrounding a vacuumified core. VIPs are the most effective insulators and have much lower thermal conductivities than conventional insulating materials such as mineral wool or polyurethane foam panels. However, VIPs do have their drawbacks such as their susceptibility to detoriation over time and their relatively high cost. Further, they cannot be cut to fit like traditional insulators since this would destroy the vacuum. They must, therefore, be ordered if non-standard sizes are required, further increasing the cost.

**Polyurethane foam insulation** is the most commonly used insulator in modern day refrigerators. It is very light and fairly cost-effecetive. Even when used in small amounts it provides excellent insulation due to its low value of thermal conductivity, allowing more space for storing items.

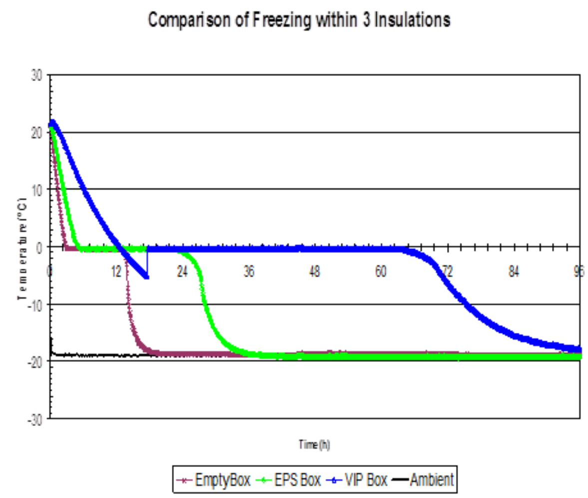


Fig. 2. Temperature vs. Time graphs for VIP and polyurethane foam insulators. Source: cryopak.com

## 3 COEFFICIENT OF PERFORMANCE

Evergy transfer occurs through three main modes in a thermoelectric system: Conduction, Convection and Radiation. In order to make worthwhile evaluations a parameter is required that is applicable for all refrigerating systems. A non-dimensionless parameter called the Coefficient of Performance is therefore used to measure the performance of a cooling machine. The Co-efficient of Performance (C.O.P) is defined as ratio between the amount of cooling provided and the electrical energy consumed.

For a refrigerator operating at maximum theoretical efficiency (Carnot efficiency), it can be shown that:

$$COP = \frac{T_{hot}}{T_{hot} - T_{cold}} \quad (1)$$

Where, $T_{hot}$ and $T_{cold}$ are the temperatures of the hot and cold reservoirs of the refrigerator respectively. In the case of a thermoelectric cooler this refers to the temperatures of the hot and cold junctions.

The Coefficient of Performance depends on values such as heat load, power applied, difference in temperature required etc. Its value usually lies between 0.3 and 0.7 for single stage devices. However, since the COP is a ratio of output to loss it is possible for it to exceed 1 unlike thermal efficiency which is a ratio of output to input. Higher values of COP are obtained when cooling is being done against a positive temperature gradient, ie the item being cooled is at a temperature above that of the surroundings. Large values of COP equate to higher values of efficiency and lower operating costs.

Shown in figure 3, for better understanding, is a normalized graph potraying the relation between COP and I/Imax (ratio of input current to the Imax value of the TE module) at different values of DT/DTmax (ratio of required temperature difference to the TE module's DTmax specification).

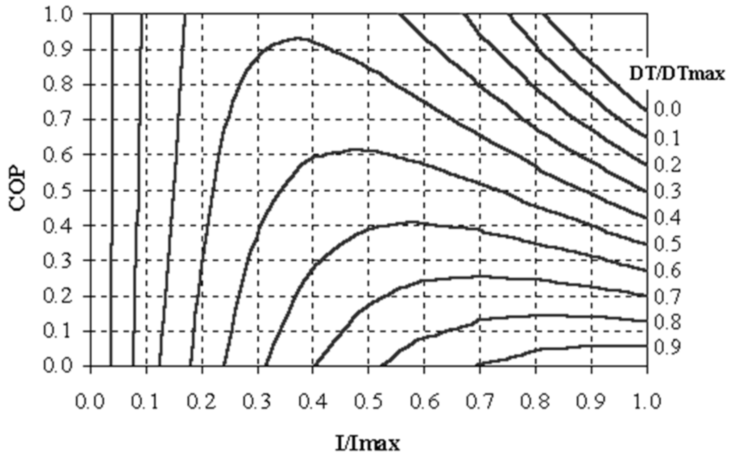


Fig. 3. Relation between COP and I/Imax at different DT/DTmax. Source: http://www.tetech.com/techinfo/images/figure3.gif

### 3.1 Phase Change Materials

Equation (1) shows that the value of COP depends on the temperature difference at which the refrigerator works. Therefore, by reducing this temperature gap, improvements in performance can be achieved. Although reducing the temperature difference might seem detrimental, it is useful in situations where extreme cooling is not required.

Phase change materials are materials that use changes in phase (melting of freezing) to absorb large amounts of heat at nearly constant temperatures. The principle behind this is that phase change materials have large values of latent heat, and hence are able to absorb a lot of heat without any change in their temperature [2].

Phase change materials (PCMs) are available at various transient temperatures (the temperature at which the phase change occurs) and can thus be used at both the hot and cold junctions of the thermoelectric cooler. By selecting PCMs with appropriate transient temperatures and large thermal storage capacities, it is possible to minimize the temperature difference across the thermoelectric cooler.

PCMs are derived from several sources and are broadly categorized into three categories [4]: Organic (naturally occurring petroleum by-products), Bio-based (fatty acids such as vegetable oils) and In-organic (engineered hydrated salt solution made from natural salts with water). Of these types, inorganic PCMs have a clear advantage over the others since they are man-made and can thus be tailored to meet specific requirements. For example, special nucleating agents are added to minimize phase change salt separation and super cooling. Traits that are otherwise characteristic of hydrated salts.

Figure 4 is a comparision between performance of thermoelectric refrigerators, with and without phase change materials. As can be seen, since the temperature of the cold junction is kept constant by the phase change material, the rate of cooling also remains constant. This is one of the major advantages of using PCMs over conventional heat sinks.

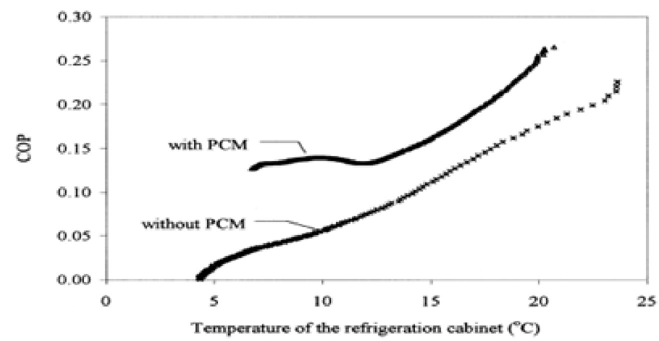


Fig. 4. COP of thermoelectric refrigerators with and without PCM ource: www.oocities.org/goelrinku/seminar.doc

## 4 Layout

In our refrigerator we incorporate the various concepts and materials discussed above. In this section we provide a detailed description of the components that we have used in our thermoelectric refrigerator.

The Thermoelectric cooler that we use has an area of 1600 $mm^2$ and a temperature difference of $70^o$ C between the hot and cold junctions. We use finned aliminium in our heat sink as a cheap yet effective [5] method to remove heat from the hot junction of the thermoelectric cooler. The heat sink is attached to the hot junction of the TE cooler and has vertical fins to aid in removal of heat. A CPU fan is used to further increase the efficiency of the heat sink by forced convection. Ceramic thermal paste is used to fill any air gaps that may be present between the thermoelectric cooler and the heat sink, thus improving the thermal contact between them.

A phase change material with a transient temperature of around $2^o$C is used as a cold sink to increase the efficiency of the refrigerator by retarding the rate at which the temperature of the cold junction drops. Further, using a PCM would help maintain the temperature inside the cooling chamber for a long time even if the current through the TE cooler is stopped (as in the case of a power outage).

## 5 Cost-analysis

The objective of our project is to meet the demand for an economical, efficient and handy refrigerator for developing countries.

In our efforts to make our refrigerator as cheap as possible we have come up with a prototype that can be commercialy sold at less than 2000 Indian rupees (roughly 20 USD). Table 2 shows the list of components used in our refrigerator and the cost of each.

TABLE 2
PRICE-LIST OF THE COMPONENTS USED IN OUR REFRIGERATOR

| S.NO. | ITEM NAME | QUANTITY | PRICE PER ITEM | TOTAL PRICE |
|---|---|---|---|---|
| 1. | Peltier plate (TE cooler) | 1 | 150 | 150 |
| 2. | Heatsink (with fan) | 2 | 270 | 540 |
| 3. | Thermal compound | 2 | 25 | 50 |
| 4. | Adapter | 1 | 250 | 250 |
| 5. | Plastic Body | 1 | 200 | 200 |
| 6. | Insulation | 2 | 100 | 200 |
| 7. | Heatsink clamps | | 50 | 50 |
| 8. | Glue,Nuts, bolts ,etc | | 50 | 50 |



## 6 CONCLUSION

In conclusion, it can be said that thermoelectric cooling is a very efficient method of cooling compact spaces. They offer several advantages over compressor based cooling systems such as ease of miniaturization, noise reduction, portability etc.

Further, refrigerators that are built based on this principle can be produced at much cheaper rates than their conventional counterparts and hence would fit well into the budgets of the people living in rural areas of developing countries, where there is a large demand for economical products that have long lives, require low maintenance and are environment friendly.

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