Project Report
on

DESIGN AND FABRICATION OF MEDICAL REFRIGERATOR USING PELTIER EFFECT FOR RURAL AREAS

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BACHELOR OF ENGINEERING
in
MECHANICAL ENGINEERING

by

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Certificate

This is to certify that the project report entitled **"Design and Fabrication of Medical Refrigerator using Peltier for rural areas"** is hereby approved as a creditable study carried out and presented by

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Abstract

Improper handling and the failure to maintain vaccines in a safe temperature range results in significant losses of vaccines in the rural developing world. This issue has reduced the success of immunization programs in the developing world, and consequently confidence in vaccinations. For vaccine refrigeration and delivery at the end stage of the cold chain, active thermoelectric cooling is a potentially viable alternative because the coolers are small and require few or no moving parts. A vaccine cooling system was constructed employing a Peltier-based thermoelectric chip (TEC) affixed to a chamber that holds the vaccine vials; The cold side of the thermoelectric module is used for refrigeration purposes, provide cooling to the vaccine chamber. On the other hand, the heat from the hot side of the module is rejected to the surroundings with the help of heat sinks and fans. With this cooler, vaccines can be maintained in the required temperature ranges of 4-12˚C, while requiring less space than a common beach cooler. This attempt of us at fabricating an eco-friendly refrigerator without having to deal with prospects of handling a dangerous refrigerant, compact in size and portable and is quite affordable.

Contents

List of Abbreviations and Symbols

Symbol/Abbreviation	Name
Q_C	Cooling capacity, W
Q_h	Heat dissipation, W
COP	Coefficient of performance
R	Semiconductor resistance, Ω
T_C	Cold side temperature, ℃
T_h	Heat side temperature, ℃
T_a	Ambient temperature
α_m	Seeback coefficient
R_m	Electrical resistance
K_m	Thermal resistance
V	Voltage, V
I	Current, I
w_{in}	Work input, w
C_p	Specific heat capacity
k	Thermal conductivity
T	Temperature
ΔT	Temperature gradient
TEC	Thermoelectric cooler
SMPS	Switch mode power supply
LPS	Linear power supply
PWM	Pulse width modulation
CFD	Computational fluid dynamics

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CHAPTER 01

INTRODUCTION

Chapter 1

INTRODUCTION

1.1 Overview

Infectious diseases are the main course of death or disability among infants and young children in rural parts. The most effective and cheapest method to prevent infectious diseases is the vaccine. These vaccines are administered into the body of patients during routine immunization programs. The most important part of these immunization programs is the cold chain system. This system implies the storing and transporting of vaccine from the manufacturer to the patient in a certain temperature for it to stay in a potent state. All vaccines lose their potency if exposed to heat or when it is frozen, so they need to be transported at certain suitable temperatures. Obviously, it is pointless to immunize with vaccine which has lost its potency .

The World Health Organization (WHO) estimates 50% of vaccines go to waste before they are administered[1]. One of the biggest contributors to this issue is the disruption in cold chain supply. That is, temperature-sensitive vaccines must be stored at 2-8 degrees Celsius to remain efficacious.

In order to deliver vaccine to patients in a potent state, the most important tool is functioning freezers and refrigerators. These cooling containers must also be rugged and find a mean to power itself as it will be used in rural parts where no electricity is available.

There are many methods used for maintain vaccine, insulin and other medicines within their required temperature ranges. One very common method utilizes re-freezable ice/gel packs to cool down the designed chamber. The cooling lifetime for these designs is dependent on the length of time that the packs stay frozen and how well the chamber is insulated. While cost is typically low, reliability of the system is an issue as they have poor temperature control that risked wastage if vaccines were exposed to temperature fluctuations.

The World Health Organization (WHO) recommends that ice packs should be “conditioned” or thawed into a slushy semi-liquid state to raise their temperature to above 2^{o}C, in the process helping to prevent risk of vaccine freezing. Nevertheless, operational studies have also suggested that the recommended practice of preconditioning or thawing can be difficult to gauge or adhere to without training. Additionally, the standard vaccine carriers suffer from design limitations that contribute to freezing risks.

The cost of most vaccines today ranges from ₹50-₹500 per administration, so wastage results in a considerable economic loss. Importantly, when vaccines lose potency, there is a loss of confidence in vaccine therapy. Thus, reducing vaccine wastage while increasing potency will provide more effective immunization in the rural, developing world at a reduced cost per dose.

One way to address aspects of the wastage issue is the development of small coolers capable of transporting vaccines, maintained in the proper temperature range, from the regional health center to the distant client; this trip is termed the end stage of the cold chain. Coolers employing phase change materials including ice are capable of maintaining the desired temperature range for a period, but vaccines in such coolers are sometimes subject to overheating or freezing because of the lack of temperature regulation.

Solid-state thermoelectric cooling, employing the Peltier effect, offers an important alternate solution to temperature-regulated vaccine refrigeration. For small loads, thermoelectric coolers offer significant advantages compared to the more conventional vapor-compression refrigeration: there are far fewer moving parts that may require maintenance, no risks of refrigerant leakage, and a lighter, more compact size.

1.2 Objective

The objective of this project work is to develop low cost, temperature regulated, portable thermoelectric refrigeration system capable of maintaining vaccine temperatures between 8 °C and 13 °C.

1.3 Background

Globally, the last-mile logistics of Covid-19 is a difficult task. The effectiveness or success of the Covid-19 vaccine is determined in their last-mile delivery with the prescribed temperature condition . The last-mile logistics of the mRNA-based Covid-19 vaccine required extremely cold temperature. The cold chain maintenance and storage of the Covid-19 vaccine have to be addressed appropriately. Especially, Gam-Covid-19 vaccination can be stored at +2 to +8 °C. Heat damage and freeze damage are the two significant challenges in the Covid-19 vaccine storage. A temperature above +8 °C could damage the vaccine quality. The result of heat damage is the permanent loss of potency, and it cannot be regained again (Government of India Ministry of Health and Family Welfare 2016). The temperature below +2 °C leads to freezing damage of vaccine. The mathematical model has been proposed for vaccine cold chain time delay between distributor and retailer. The distributors and retailers should maintain the appropriate cold chain to avoid vaccine degradation . In Norway, various cold containers are investigated for their transportation cost and CO_2 emission. The various simulation and analysis studies concluded that a small box van (micro cold storage) has significant potential for CO_2 emission reduction .

The most common passive refrigeration systems rely on the combination of an insulated container with coolant packs like Ice packs or Phase Change Material packs acting as thermal batteries (Fig- 1.1). A container is efficiently thermally insulated when heat exchange between its interior and exterior is minimized.

The World Health Organization (WHO) recommends that ice packs should be “conditioned” or thawed into a slushy semi-liquid state to raise their temperature to above 2^{o}C, in the process helping to prevent risk of vaccine freezing. Nevertheless, operational studies have also suggested that the recommended practice of preconditioning or thawing can be difficult to gauge or adhere to without training. Additionally, the standard vaccine carriers suffer from design limitations that contribute to freezing risks; they do not have built-in partitions or barriers to prevent direct contact between vials and the ice packs.

Due to the Covid-19 pandemic, the surge in the increase of medical freezer is enormous in quality to regulate vaccine delivery.

Figure 1.1 Convectional Ice based storage box.

1.3.1 Product Research

Table 1.1 summarizes the product research . In completing our research of similar products on the market, a few common observations and insights were made that will help guide our initial design phase. Firstly, a lot of commercially available refrigeration units are large and meant for storage of large quantities of vaccines at the hospital itself. There are not many portable coolers designed with the intent of transporting vaccines far distances to remote villages. Also, the solar coolers that are available are incredibly expensive, often times costing upwards of around 1.5 lakhs.

Table 1.1 Existing products that solve similar problems.

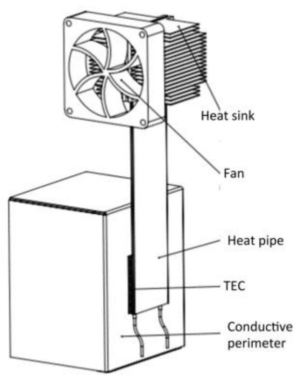
Product: Sure Chill **Pros:** Portable, stays cool for long time. **Cons:** Bulky, difficult to attach to motorcycle, expensive. **Functionality:** Water surrounds a Sure Chill refrigeration compartment. When it has power, the water cools and forms ice above the compartment leaving only water at four degrees cooling the contents. When the power is switched off, the water warms and rises while the ice begins to melt, keeping only four-degree water cooling the contents of the compartment	

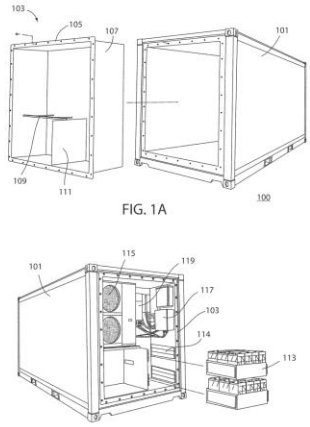
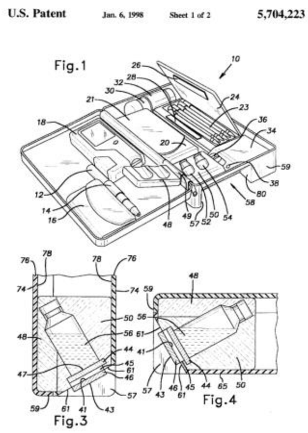
Product: Isobar **Pros:** Lightweight, portable, stays cool for long time. **Cons:** Expensive . **Functionality:** A mix of ammonia and water is heated in a lower pressure vessel, causing the ammonia to vaporize and separate from the water. It remains trapped in the upper chamber by a valve until the cooling effect is needed. The device is then flipped over, causing the chemicals to recombine and give a cooling effect.	
Product: Indigo **Pros:** Lightweight, portable, stays cool for long time. **Cons:** Difficult to recharge, expensive. **Functionality:** The vessel is a liquid nitrogen (a doubled-walled bottle with vacuum insulation that is much like a thermos), with multi-layer insulation technology (aka: the material that protects spaceships from extreme temperatures). It functions as an ultra-insulated cooler.	
Product: Emvolio **Pros:** Lightweight, portable, stays cool for long time. **Cons:** Very expensive. **Functionality:** It is battery powered refrigerator. Insulated cooling chamber is employed with refrigeration mechanism using solid-state cooling with a smart PID (Proportional Integral Derivate) controller. Desired temperature can be set by user through control panel.	

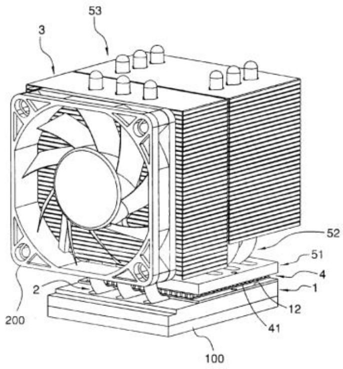
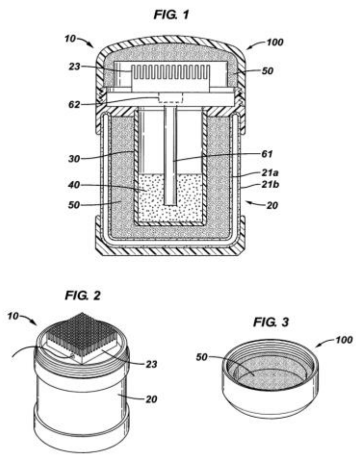
1.3.2 Technical Research

Table 1.2 summarizes five patents that are integral to the functionality of the solar cooler. Our goal is to design a cooler that is driven by the thermo-electric cooling effect of Peltier technology. A Peltier is a thermo-electric cooler that works when DC current flows through small, doped semiconductors that are arranged in series between two ceramic plates. One side of the Peltier heats up while the other side cools down. Usually, heat is dissipated through a heat sink or some type of circulating water system. This creates the desired temperature on the cold side of the Peltier [6]. Peltiers are an appealing option when deciding how to effectively cool a vaccine transport cooler due to their low cost, no moving parts, and durability.

Table 1.2 Related Technical Patents

Patent Title	Patent Number	Patent Description	Drawing
Mobile Thermoelectric Vaccine Cooler with a Planar Heat Pipe	US20160003503A1	A portable medical refrigerator cooled with a thermoelectric device connected to a heat sink. Also utilizes a planar heat pipe to efficiently transfer heat out of the cooling chamber.	

Backpack for use with a Portable Solar Powered Refrigeration Box and Water Generator	US20180106509A1	A Solar powered portable refrigeration unit with an insulated chamber for storing perishable goods. Contains batteries and an inverter to convert DC voltage to AC voltage. Also contains a stand-alone water generation unit for converting atmospheric moisture to potable water.	
Thermoelectric Medicine Cooling Bag	US5704223A	Medicine cooling bag cooled by a Peltier heat pump. Vials of medicine are tilted to maximize heat transfer efficiency. The heat pump has both a cold plate and heat sink and is powered by an internal battery.	

Two Stage Radiation Thermoelectric Cooling Apparatus	US6880346B1	Two stage thermoelectric cooling apparatus for cooling electrical components. First stage pre-cools the electronic device in order to lower the temperature to level the TEC can efficiently cool. Residual heat is dissipated out the back of the device using a heat pipe and radiator.	
Medical Travel Pack with Cooling System	US20090049845A1	Device incorporates a thermoelectric cooler inside an insulated cooler. TEC is in contact with a freezable phase change material. When disconnected the phase change material provides passive cooling inside the container while medical material is transported. Not solar powered, is intended for short trips in between charges.	

1.4 Proposed Solution

Solid-state thermoelectric cooling , employing the Peltier effect, offers an important alternate solution to temperature-regulated vaccine refrigeration. For small loads, thermoelectric coolers offer significant advantages compared to the more conventional vapor-compression refrigeration: there are far fewer moving parts that may require maintenance, no risks of refrigerant leakage, and a lighter, more compact size.

The main system consisted of thermoelectric module as cooling generator along with insulated chamber, battery and charging unit. A Thermoelectric Cooling Module (TECM) is defined as a solid-state heat pump. When DC power is applied to the module, heat is moved from the cold surface to the hot surface. The cold side of the thermoelectric module is used for refrigeration purposes; provide cooling to the vaccine chamber.

1.5 Marketing features

- Desired temperature can be maintained.
- Economical and easy on budget.
- Lightweight and can be carried out easily.
- Portable and mobile, which makes it easy to use.
- Environment friendly due to no uses of gases.
- Safe and easy to use because of features.

CHAPTER 02

LITERATURE REVIEW

Chapter 2

LITERATURE REVIEW

2.1 Previous Work

1] Jun Luo,Lingen Chen,Fengrui Sun,Chih Wu (2003)

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. [1]

2] Amir Yadollah Faraji , H.J. Goldsmid b , Aliakbar Akbarzadeh (2013)

To study COP and other cooling parameters of a thermoelectically-driven liquid chiller, a 430 ml capacity liquid chiller incorporating two commercially available thermoelectric modules as its active components (fig. – 01), has been designed, built and assessed. The system can use natural or forced air convection in heat exchangers attached to the thermoelectric module surfaces. Results show that the system can readily be used for water chilling with a COP between 0.2 and 0.8 in order to achieve a temperature of 5–15 C below ambient. Further increase in COP may be feasible through improving system components especially the Heat exchangers. In addition, forced air convection heat exchangers showed better COP and CDP compared with natural convection heat exchangers. Liquid cooling can be applied on hot side of thermoelectric module to increase the COP.[2]

3] Ajitkumar N. Nika (2014)

Explained about the research and development work carried out by different researchers on development of novel thermoelectric Air conditioning system. In recent years, 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 has become a subject of great concern and resulted in extensive research into development of novel refrigeration and space conditioning technologies. There are several different types of cooling devices available to remove the heat from industrial enclosures, but as the technology advances, thermoelectric cooling is emerging as a truly viable method that can be advantageous in the handling of certain small-to-medium applications.[3]

4] Murat Gökçek, Fatih Şahin (2017)

In this paper, they examined the thermal performance of thermoelectric refrigerator utilising minichannel heat sink. They studied the effect of minichannel heat sink experimentally for different flow rates of cooling water utilised in heat sink. Their result shows that COP of thermoelectric refrigerator increases with increasing the flow rates of cooling water. They evaluated the values of COP for different flow rates such as 0.8 L/min, 1 L/min, 1.5 L/min and different electrical input of 8 V and 12 V. They concluded that the greater the difference between ambient temperature and inside temperature of thermoelectric refrigerator more will be the power consumption of refrigerator. This study concludes that the performance of minichannel heat sink used in this study has as good as other liquid water cooled systems used to absorb heat from thermoelectric modules hot side.[4]

5] Yasser Abdulrazak Alghanima , Osama Mesalhy (2022)

In this paper, Experimental study and CFD analysis of the thermal behavior of TE compartment, which is one of the compartments of a hybrid household-refrigerator, were performed. The hybrid refrigerator was made of the thermoelectric and vapor-compression technologies. In the computational simulation, the effect of changing the speed of the cold-side fan on the performance of the TE compartment was studied.

Moreover, the effect of generating vertical slots with different numbers and widths in the cold-side heat sink was investigated. Obtained results showed that:

- Increasing the fan rotational speed from 500 to 2000 rpm improved COP_{TER} by about 20%.
- Increasing the number and width of the slots improved the temperature uniformity with a small effect on COP_{TER}.[5]

2.2 Comparative Study

The authors developed a DC portable refrigerator with the aim and objective to store the food and perishable items particularly medicines. The project was based on a vapor-compression system which is explained before in this chapter. The main components of the refrigerator were a condenser, a compressor, a capillary tube, and an evaporator. The project was focused on their length and at the end of the project, the length of the capillary tube was 2.84 meters, a condenser is 12.39 meters, and an evaporator is 9.25 meters. A small DC refrigerator has been tested but cannot work properly because of the electronic unit problem.[6]

The authors of a study improved the efficiency of a portable refrigerator by using the outside cold air. They explored that the highest energy consumption stage is the usage phase and it is in the form electricity running the compressor 80-90% of the time so they introduced the sheer volume technique to reduce the power consumption but the research has some limitations like it can also be used in the kitchen with modifications for the energy-efficient environment and at places with cold climates.[7]

The review of another study showed that the authors worked to design and develop a portable refrigerator particularly for home use. The design and mechanism were based on a vapor compression system and it used tetrafluoroethylene (R134a) refrigerant. The maximum volume it could accommodate was 0.041m2 and it could achieve the temperature of 7 Celsius degree. The body was made up of steel plates and plastic foam was used for insulation purposes. At the end of the fabrication, the test was run and results showed that the refrigerant was wet vapor and the coefficient of performance was calculated as 7.81. The heat rejected by the condenser and work is one on the compressor were obtained as 176.81 kJ/kg and 20.07 kJ/kg which was quite a good output.[8]

The project under consideration is different from the above-stated projects concerning a few points: It is positioned as a desktop refrigerator (horizontal top-lid) as against the tower one which would increase its efficiency by keeping the coolness inside it every time it is opened. Also, it reaches the lower temperature in lesser time than in the projects which is 6 Celsius degrees in 30 minutes when there is nothing in it and takes a bit longer when something is inside there. It is energy efficient as compared to those refrigerators that are mentioned above. In one of the projects mentioned, there was an operational issue because of unit disturbance which is not the case here. This project works very well and is well functional

CHAPTER 03

METHODOLOGY

Chapter 3

METHODOLOGY

3.1 Work Plan

- These are some of the important tasks that would be performed during this research.
  - Understanding the basic concepts of thermoelectric cooling.
  - Study of the existing CPU cooling techniques .
  - Literature review regarding the topic and study about the effect due dimples along the flow of water.
  - Deciding the various parameters for which system has to be designed.
  - Deciding about the thermoelectric module which will produce the desired cooling effect.
  - CAD Design of the experimental set up and identification of the various equipments to be required.
  - CFD analysis of experimental setup.
- Market survey for all the required equipments.
- Procurement of the Material/equipments.
- Preparation of experimental set up.
- Carrying out experiments and obtaining the results.
- Analysis of results.
- Checking out the performance of the thermoelectric module used.
- Fabrication of Model.

3.2 Design Considerations (Needs and Wants)

We focus on conceptual development of a device to store vaccines in last mile delivery for specific temperature range, which can work standalone, have good portability.

In analyzing the root of the problem, the approach should be to design a device which can powered with both 12V DC supply & 230V AC Supply. Charging ports of cars, two-wheelers can be used to powered the device in transportation. The most important need is of maintaining the optimal temperature of the vaccines.

The vaccine cold box was designed to proceed with this study. The factors that should be considered in the design process are as follows:

- Design of structure which can be easily transported.
- Build low-cost design.
- Have temperature controlling and monitoring system.
- Build a portable light-weight box.
- Can be powered through Cars & two-wheelers charging socket.

Table 3.1 Possible wants and needs wants for vaccine cooler.

Need	**Want**
Maintains optimal temperature	Cheap
Safely transports vaccines	Easy to operate
Portable	Durable
Has off-grid power option	Can be connected in regular AC outlet
Minimal maintainance	Can be connected to car and two-wheeler DC outlet

CHAPTER 04

TYPES OF REFRIGERATION SYSTEMS

Chapter 4

TYPES OF REFRIGERATION SYSTEMS

4.1 Different types of refrigeration systems are:

4.1.1 Vapor Compression Refrigeration –

Vapor compression system consists of majorly four equipment's , Evaporator, compressor, condenser, and expansion valve**.** In evaporator refrigerant is evaporated from liquid to vapor and produces refrigerating effect. The evaporated vapor goes to compressor and it is compressed to higher pressure level and then passed to condenser for cooling. Condenser cools refrigerant from vapor to liquid phase with the use of atmospheric temperature or cooling water temperature. The liquid refrigerant is passed to expansion valve where refrigerant of high pressure is expanded to low pressure and fed to evaporator for next cycle of refrigeration.
Vapor compression system is most reliable refrigeration system and used is household refrigerators, Air conditioners. The COP of vapor absorption system is high which makes is economical in wide range of operation.

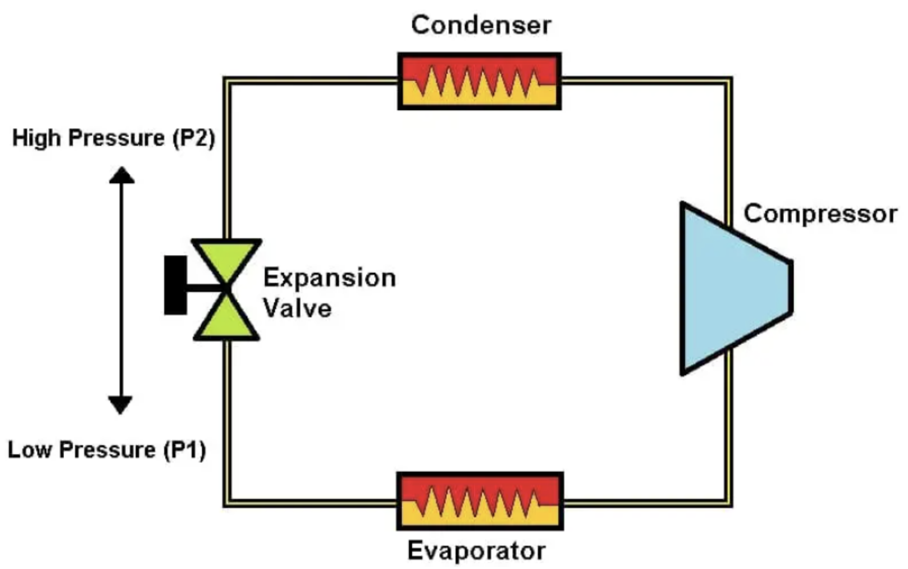


Figure 4.1 Vapor Compression Refrigeration Cycle.

4.1.2 Vapour Absorption Refrigeration –

Vapor absorption system utilizes heat for producing refrigeration in place of electricity. It consists of absorber, Generator, condenser expansion valve and evaporator. The refrigerant in evaporator evaporates and goes to absorber where it is absorbed by absorber fluid. absorber fluid is pumped to generator where refrigerant is separated and sent to condenser for condensation. condensed refrigerant is passed to expansion valve and this refrigeration cycle continues to produce refrigeration.

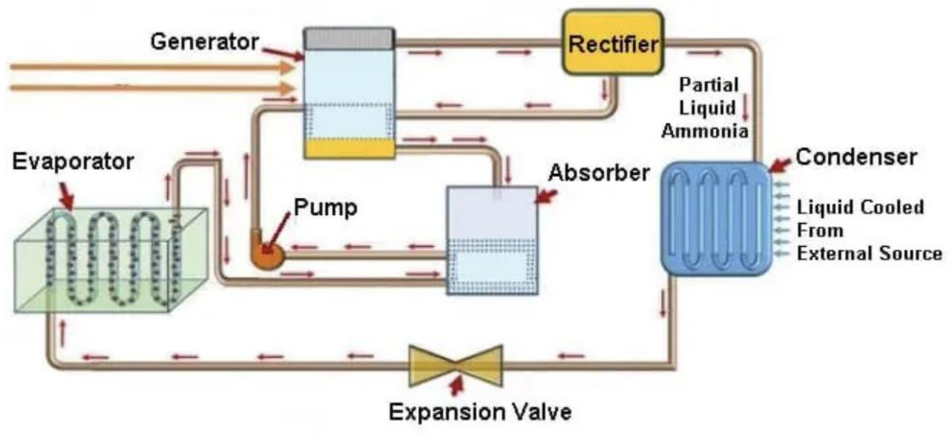


Figure 4.2 Vapour Absorption Refrigeration Cycle.

4.1.3 Air Refrigeration –

Air refrigeration is based on Bell-Coleman Cycle or Reversed Brayton Cycle, In air refrigeration system air is used as working fluid, No phase change is involved in air refrigeration, It is used in air craft as high pressure air is readily available.

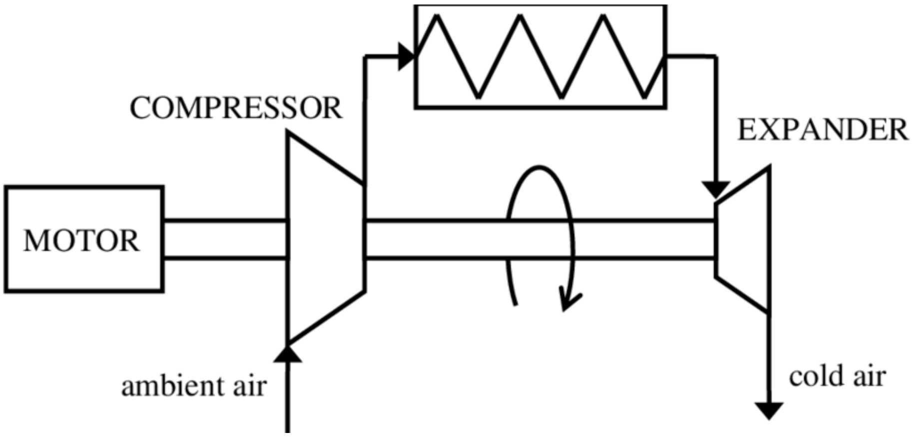


Figure 4.3 Air Refrigeration Cycle.

4.1.4 Thermoelectric Refrigeration –

These systems do not need water or any type of refrigerant. They rely on a thermocouple and electric current. Thermoelectric refrigeration uses a principle called the "PELTIER" effect to pump heat electronically, when an electrical current is applied across the junction of two dissimilar metals, heat is removed from one of the metals and transferred to the other. This is the basis of thermoelectric refrigeration. The cold side of the thermocouple is placed in the area that needs cooled so it can attract heat and remove it from the air. Thermoelectric refrigeration isn't usually used for large cooling loads, but it's perfect for hard-to-access small cooling loads.

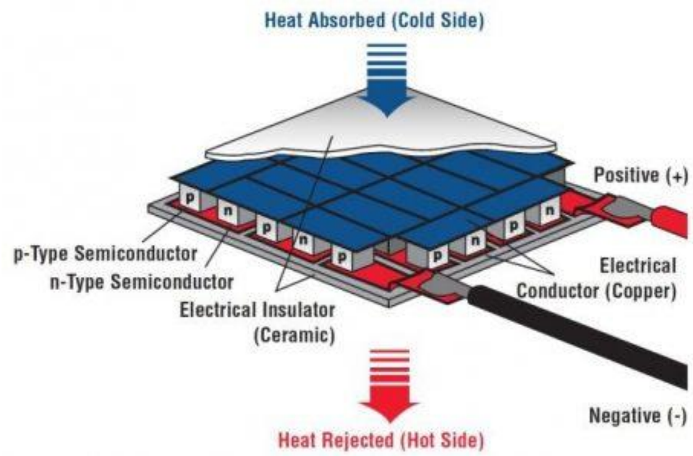


Figure 4.4 Thermoelectric Cooling System

CHAPTER 05

THERMOELECTRIC REFRIGERATION

Chapter 5
THERMOELECTRIC REFRIGERATION

5.1 Introduction

Thermoelectric cooling uses the Peltier effect to create a heat flux at the junction of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other, with consumption of electrical energy, depending on the direction of the current. Such an instrument is also called a Peltier device, Peltier heat pump, solid state refrigerator, or thermoelectric cooler (TEC).

This technology is far less commonly applied to refrigeration than vapor-compression refrigeration is. The primary advantages of a Peltier cooler compared to a vapor-compression refrigerator are its lack of moving parts or circulating liquid, very long life, invulnerability to leaks, small size, and flexible shape.

5.2 Thermoelectric Effects

5.2.1 Seeback Effect: The Seebeck effect was discovered by Thomas Seebeck in 1821. It is associated with the generation of a voltage along a conductor subject to a temperature gradient ΔT=T2-T1 .If a temperature gradient applies to a conductor, an electromotive force ΔV=V2-V1 will occur between the hot and cold ends due to charge carrier diffusion.

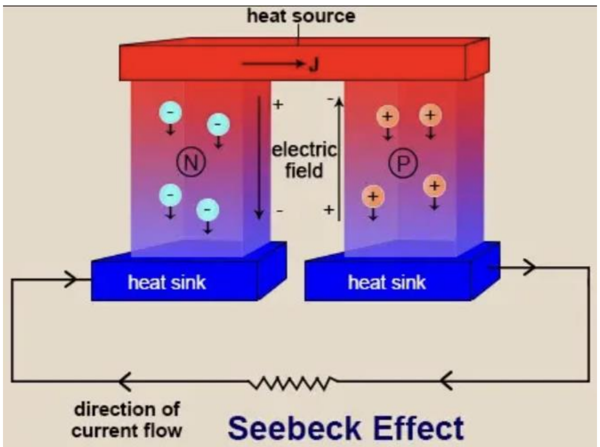


Figure 5.1 Seeback Effect

5.2.2 Peltier Effect*:* 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 as shown in figure. The heat absorbed or released at the junction is proportional to the input electric current. The constant of proportionality is called the Peltier coefficient.

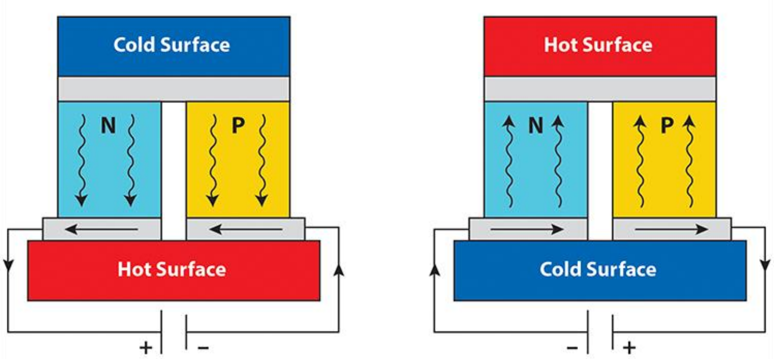


Figure 5.2 Peltier Effect

5.3 Operating Principle

Thermoelectric coolers operate by the Peltier effect (one of three phenomena that make up the thermoelectric effect). A thermoelectric module is made from three components; the conductors, legs, and the substrate, and many of these modules are connected electrically in series, but thermally in parallel. When a DC electric 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 special applications, multiple coolers can be cascaded or staged together for lower temperature, but overall efficiency (COP) drops significantly. The maximum COP of any refrigeration cycle is ultimately limited by the difference between the desired (cold side) and ambient (hot side) temperature (the temperature of the heat sink). The higher the temperature difference (delta), the lower the maximum theoretical COP.

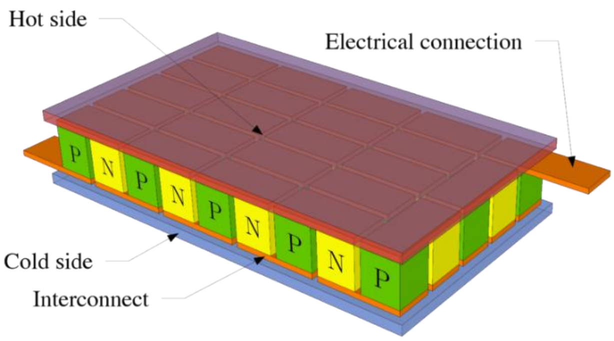


Figure 5.3 Peltier element schematic.

5.4 Advantages of Thermoelectric Cooling

- **No Moving Parts**: A TE module works electrically without any moving parts so they are virtually maintenance free.
- **Small Size and Weight:** The overall thermoelectric cooling system is much smaller and lighter than a comparable mechanical system. In addition, a variety of standard and special sizes and configurations are available to meet strict application requirements.
- **Ability to Heat and Cool With the Same module:** Thermoelectric coolers will either heat or cool depending upon the polarity of the applied DC power. This feature eliminates the necessity of providing separate heating and cooling functions within a given system.
- **High Reliability:** Thermoelectric modules exhibit very high reliability due to their solid-state construction. Although reliability is somewhat application dependent, the life of typical TE coolers is greater than 200,000 hours.
- **Electrically "Quiet" Operation:** Unlike a mechanical refrigeration system, TE modules generate virtually no electrical noise and can be used in conjunction with sensitive electronic sensors. They are also acoustically silent.
- **Environmentally Friendly:** Conventional refrigeration systems cannot be fabricated without using chlorofluorocarbons or other chemicals that may be harmful to the environment. Thermoelectric devices do not use or generate gases of any kind.

5.5 Disadvantages of Thermoelectric Cooling

- Advantageous only for unit smaller capacity.
- More power is needed to run the system.
- Low COP.

5.6 Thermoelectric cooling versus traditional refrigeration

Solid state design

- No moving parts
- Integrated chip design
- No hazardous gases
- Silent operation

Compact and lightweight

- Low profile
- Size to match to components footprint
- No bulky compressor units

Precise temperature stability

- Tolerences of better than +/- 0.1^{o}C.
- Accurate reproducible ramp

Cooling/heating mode options

- Fully reversible with switch in polarity

Rapid response time

- Instantaneous temperature change

CHAPTER 06

EXPERIMENTAL WORK

Chapter 6
EXPERIMENTAL WORK

6.1 Components Used

In this project, various equipment and materials are used for the proper functioning and performance of the refrigerator. These equipment and materials are as follows:

- Thermoelectric Peltier Module
- Temperature Controller (Thermostat)
- Heat Sink
- Cooling fans
- Thermal Grease
- Switch Mode Power Supply (SMPS)
- Battery
- PWM Controller
- Insulated cooling chamber
- Multimeter
- Composite Sheet for fabrication

6.1.1 Thermoelectric Peltier Module

We used one TEC 12706 peltier unit. This unit works on 12 Volts DC power supply and draws Maximum current of 3.4 amps. The power rating of this unit is 40 watts.

Figure 6.1 TEC-12706 Peltier Module

6.1.2 Cooling Fan

We are using two cooling fans respectively mount on each heatsink. Main purpose of cooling fan to dissipate heat by forced convection. One fan is of 9 inches and another one is of 4 inch which works on 12V DC supply and draws 0.18 amps each. The power consumption of each fan is 2.1 watts.

Figure 6.2 Cooling Fan

6.1.3 Heat Sink

A heat sink is a passive heat exchanger that cools a device by dissipating heat into the surrounding medium with the help of fan mounted over it. The heat sink is generally made up of aluminum. Heat sinks are heat exchangers such as those used in refrigeration and air conditioning systems, or the radiator in an automobile.

Figure 6.3 Heat Sink

A heat sink is designed to increase the surface area in contact with the cooling fluid surrounding it, such as the air. Approach air velocity, choice of material, fin (or other protrusion) design and surface treatment are some of the factors which affect the thermal performance of a heat sink. Heat sinks are used to cool computer central processing units or graphics processors. Heat sink attachment methods and thermal interface materials also affect the eventual die temperature of the integrated circuit. Thermal adhesive or thermal grease fills the air gap between the heat sink and device to improve its thermal performance.

Basic Heat Sink Heat Transfer Principle

A heat sink transfers thermal energy from a higher-temperature device to a lower-temperature fluid medium. The fluid medium is frequently air, but can also be water, refrigerants or oil. If the fluid medium is water, the heat sink is frequently called a cold plate. In thermodynamics a heat sink is a heat reservoir that can absorb an arbitrary amount of heat without significantly changing temperature. Practical heat sinks for electronic devices must have a temperature higher than the surroundings to transfer heat by convection, radiation, and conduction.

Consider Fourier's law of heat conduction. Fourier's law of heat conduction shows that when there is a temperature gradient in a body, heat will be transferred from the higher temperature region to the lower temperature region. The rate at which heat is transferred by conduction, q_k, is proportional to the product of the temperature gradient and the cross-sectional area through which heat is transferred. When it is simplified to a one-dimensional form in the *x* direction, it can be expressed as:

$$q_k = -kA\frac{dt}{dx}$$

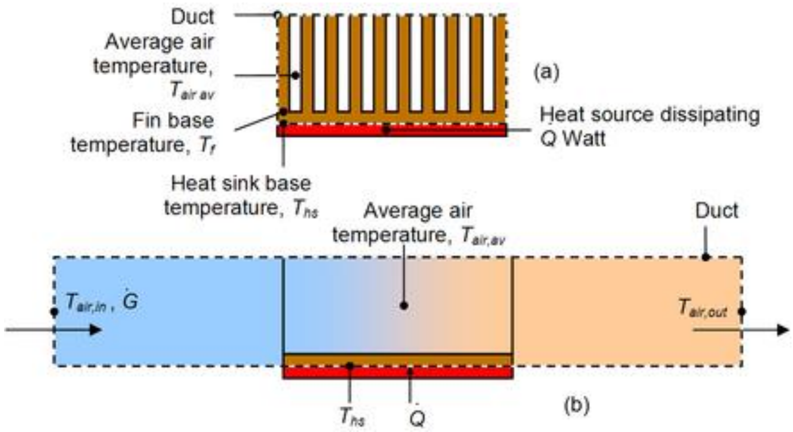


Figure 6.4 Heat Sink Configuration

For a heat sink in a duct, where air flows through the duct, the heat-sink base will usually be hotter than the air flowing through the duct. Applying the conservation of energy, for steady-state conditions, and Newton's law of cooling to the temperature nodes shown in the diagram gives the following set of equations:

$$\dot{Q} = \dot{m}_{Cp,in}(Tair,out - Tair,in)$$

$$\dot{Q} = \frac{Ths - Tair,av}{Rhs}$$

Where,

$$Tair,av = \frac{Tair,in + Tair,out}{2}$$

$\dot{m}$ is the air mass flow rate in kg/s

$c_{p,\mathrm{in}}$ is the specific heat capacity of the incoming air, in J/(kg °C)

R_{hs} is the thermal resistance of the heatsink

Using the mean air temperature is an assumption that is valid for relatively short heat sinks. When compact heat exchangers are calculated, the logarithmic mean air temperature is used.

The above equations show that:

- When the air flow through the heat sink decreases, this results in an increase in the average air temperature. This in turn increases the heat-sink base temperature. And additionally, the thermal resistance of the heat sink will also increase. The net result is a higher heat-sink base temperature.

- The increase in heat-sink thermal resistance with decrease in flow rate will be shown later in this article.
- The inlet air temperature relates strongly with the heat-sink base temperature. For example, if there is recirculation of air in a product, the inlet air temperature is not the ambient air temperature. The inlet air temperature of the heat sink is therefore higher, which also results in a higher heat-sink base temperature.
- If there is no air flow around the heat sink, energy cannot be transferred.
- A heat sink is not a device with the "magical ability to absorb heat like a sponge and send it off to a parallel universe".

Natural convection requires free flow of air over the heat sink. If fins are not aligned vertically, or if fins are too close together to allow sufficient air flow between them, the efficiency of the heat sink will decline.

6.1.4 Temperature Controller

For temperature control we have used Thermostat (W1209). Thermostats are devices that sense the temperature of a system so that the temperature is maintained at the desired set point or near to it. W1209 thermostat module has a temperature sensor, keys, LED display, relay and requires DC 12V power supply. NTC temperature sensor allows the module to intelligently control varied electrical devices based on the temperature. NTC thermistor has a negative temperature coefficient, which means the resistance decreases with increasing temperature.

Specification of W1209 are as follows :

- Temperature Control Range: -50 ~ 110 C
- Refresh Rate: 0.5 Seconds
- Input Power (DC): 12V
- Measuring Inputs: NTC
- Current consumption =65mA

Figure 6.5 W1209 Thermostat

6.1.5 Switch Mode Power Supply (SMPS)

A switched-mode power supply (switching-mode power supply) is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently. The disadvantages of Linear Power Supply(LPS) such as lower efficiency, the need for large value of capacitors to reduce ripples and heavy and costly transformers etc. are overcome by the implementation of Switched Mode Power Supplies.

SMPS transfers power from a DC or AC source to DC loads.

Specifications of SMPS used are as follows :

Output Amps	10 A
Output Volts	12 V
Input Volts	110/ 220V AC
Output Port	Terminal Screw

Figure 6.6 SMPS 12V 10A

6.1.6 Battery

A battery is a device that converts chemical energy contained within its active materials directly into electric energy by means of an electrochemical oxidation-reduction (redox) reaction.

We are using 12V, 7Ah Sealed Lead Acid battery.

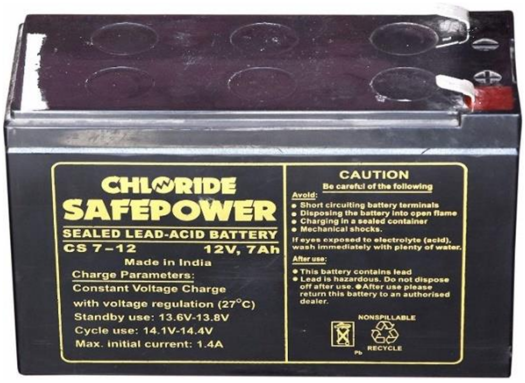


Figure 6.7 W1209 Thermostat

6.1.7 PWM Controller

Pulse-width modulation (PWM) is a powerful technique for controlling analog circuits with a microcontroller's digital outputs. PWM is used in many applications, ranging from communications to power control and conversion. For example, the PWM is commonly used to control the speed of electric motors, the brightness of lights, in ultrasonic cleaning applications, and many more.

A PWM is basically a digital unipolar square wave signal where the duration of the ON time can be adjusted (or modulated) as desired. This way the power delivered to the load can be controlled from a microcontroller.

Figure 6.8 W1209 Thermostat

6.1.8 Thermal Grease

Thermal grease is primarily used in the electronics and computer industries to assist a heat sink to draw heat away from a semiconductor component such as IC‘s.

Thermally conductive paste improves the efficiency of a heat sink by filling air gaps that occur when the imperfectly flat and smooth surface of a heat generating component is pressed against the similar surface of a heat sink, air being approximately 8000 times less efficient at conducting heat than, for example, aluminum (a common heat sink material). Surface imperfections and departure from perfect flatness inherently arise from limitations in manufacturing technology and range in size from visible and tactile flaws such as machining marks or casting irregularities to sub-microscopic ones not visible to the naked eye. Thermal conductivity and "conformability" (i.e., the ability of the material to conform to irregular surfaces) are the important characteristics of thermal grease.

In compounds containing suspended particles, the properties of the fluid may well be the most important. As seen by the thermal conductivity measures above, the conductivity is closer to that of the fluid components rather than the ceramic or metal components. Other properties of fluid components that are important for thermal grease might be:

- How well it fills the gaps and conforms to both the components and the heat sink's uneven surfaces.
- How well it adheres to those surfaces.
- How well it maintains its consistency over the required temperature range.
- How well it resists drying out or flaking over time.
- Whether it degrades with oxidation or breaks down over time.

6.1.9 Insulation Material

We have used Thermocol Box insulation for cooling chamber. Thermocol is light in weight and it has good thermal insulation property. the ice vendors take advantage of thermocol for its economic value and good insulation property as it does not allow the inner temperature of cooling medium to go down. Hence it is also an economic source of insulation.

6.2 Load Calculations

The heat load calculations were carried out to determine the capacity of the system. The following parameters were considered for determining the cooling load calculations. They are: Product load & Transmission load

6.2.1 Transmission Load -

Heat transfer through insulation by conduction and convection through insulated walls,

$$Qi = \frac{A(Ta - Tc)}{(\frac{1}{h}) + (\frac{t}{K})}$$

Where,

Ambient temperature, Ta=40°C

Lowest desired temperature, Tc =7°C,

Insulation thickness, t=40mm=0.02m,

Thermal conduction of poly urethane foam, K=0.025W/mk

Convective heat transfer coefficient, h=25W/m^2 K

Area of insulation, A= 2(L*B) +2(L*H) +2(B*H)

= 2(0.1*0.01) +2(0.1*0.05) +2(0.01*0.05)

= 0.64 m^2

Heat transfer through insulated walls,

$$Qi = \frac{A(Ta - Tc)}{(\frac{1}{h}) + (\frac{t}{K})}$$

$$Qi = 0.64 \times \frac{(37 - 7)}{\left(\frac{0.02}{0.025}\right) + \left(\frac{1}{25}\right)}$$

$$Qi = 22.8 \text{ W} \qquad (1)$$

6.2.2 Product Heat load-

The quantity of heat to be removed from the products inside the refrigerated space is known as the product load.

Water is used in place of vaccine for taking measurements and calculation.

it was found that the inner temperature of the refrigeration area was reduced from 34˚C to 7 ˚C in approximately 60 min.

Properties of Water are – (density = 1 kg/L and C_P = 4187 J/kgK)

Volume = 500 l

Mass of water, m = density × volume = 1 × 0.5 = 0.5 kg

Total heat removed from the water ,

$$Q_c = mC_P\Delta T$$

$$Q_c = 67829.4\ J$$

Total Heat Removed from Water , $Q_c = \frac{Q}{t}$, (t = time req. for cooling)

Qc = 13.9 W (2)

Total Heat Removed, **Qt** = Qi + Qc = 22.8 + 13.9 = **36.7 W** (3)

The work input required in the cooling process is determined by,

W_{in} = Input power + fan power

= (3.6 × 13) + 0.36

W_{in} = 46.98 w (4)

6.2.3 Determining COP of system -

COP is an important index for evaluating the refrigeration performance of thermoelectric refrigeration devices. COP is defined as the ratio of the total cooling capacity of the equipment to the total energy consumption.

Practical COP of peltier system can be determined by –

$$COP = \frac{Refrigerating\ Effect}{Work\ input}$$

$$COP = \frac{Qt}{w_{in}} \tag{5}$$

In Equation (5), Q_t can be calculated according to equation (3), and W_{in} can be calculated as equation (4). Therefore,

$$COP = \frac{36.7}{46.9}$$

COP = 0.78

6.3 Heat removing capacity of peltier module (Q_1)

The quantity of heat pumped by the module is obtained from,

$$Q1 = (\alpha_m \times I \times T_c) - \left(\frac{I^2}{2} \times R_m\right) - K_m \times (T_h - T_c)$$

The tests conditions -

Peltier maximum current, Imax = 6.4A

Peltier maximum voltage, Vmax =15.4V

Peltier maximum cooling capacity, Qcmax = 53.3W

ΔTmax = 66°C

Resistance of peltier module, R = 1.98Ω

Ambient temperature, Th = 37°C = 310 K

Cooling temperature, Tc = 7°C = 280 K

Seeback Coeffieient of TEC, α_m

Electrical Resistance of TEC, R_m

Thermal Resistance of TEC, K_m

$$\alpha_m = \frac{v_{\max}}{T_h} = \frac{14.4}{310} = 0.046\ v\ /\ k$$

$$R_m = \frac{T_h - \Delta T_{\max}}{T_h} \times \frac{V_{\max}}{I_{\max}} = 1.77\ \Omega$$

$$K_m = \frac{T_h - \Delta T_{\max}}{2\Delta T_{\max}} \times \frac{V_{\max}}{I_{\max}} \times I_{\max} = 0.5495\ w\ /\ k$$

$$Q1 = (\alpha_m \times I \times T_c) - \left(\frac{I^2}{2} \times R_m\right) - K_m \times (T_h - T_c)$$

$$Q1 = (0.046 \times 3.4 \times 280) - \left(\frac{3.4^2}{2} \times 1.77\right) - (0.549 \times (310 - 280))$$

$$\boldsymbol{Q1 = 17.03\ w}$$

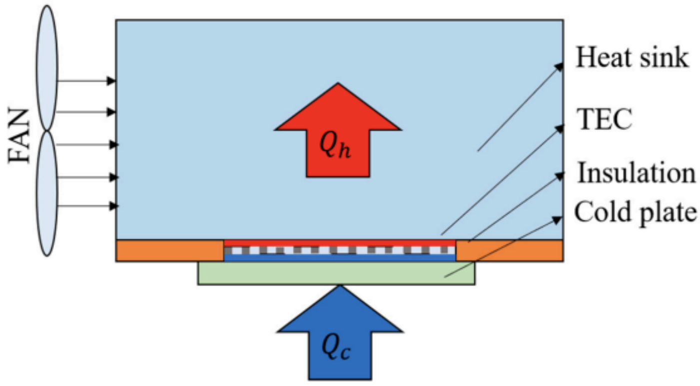


Figure 6.9 Schematic diagram of thermoelectric refrigeration model

6.4 Fabrication of Refrigerator

1. Firstly, a box of composite sheet is made of given dimensions and then the inner walls of the box is covered with thermocol insulation.
2. Heat sinks are attached to peltier on cool side and hot side and thermal grease is filled between the surface of peltier and heat sink for proper thermal flow.
3. 9-inch cooling fan is attached on hot side of heat sink to dissipate the hoeat of heatsink into outer atmosphere i.e., out of the insulation box, so the hot side of Peltier unit is unable to affect cold side of Peltier unit.
4. 4-inch small cooling fan is attached to cold side of peltier which is inside cooling box to dissipate the cooling effect inside the cooling chamber.

5. All the electrical connections are made as per circuit diagram. SMPS is used to powered the peltier unil also 12 Volts, 7 Ah battery is connected in parallel with peltier unit to power the peltier unit when external power source is not available.
6. Thermostat is connected in circuit and NTC sensor is placed inside cooling box to maintain and display the temperature set by the user.
7. Thermostat is set by user to maintain the desired temperature.
8. All electrical connections are made stronger by soldering them.

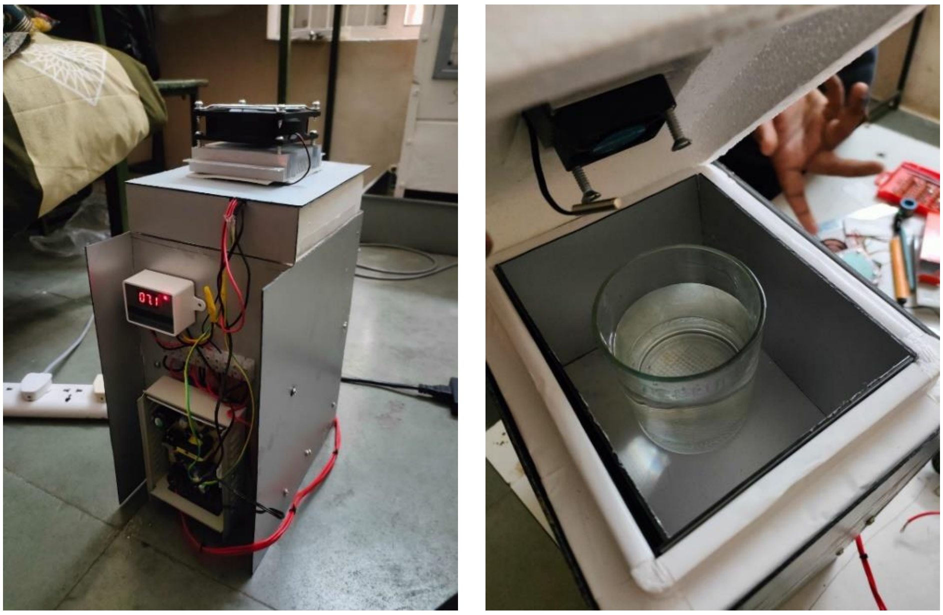


Figure 6.10 Experimental Setup of Refrigerator

Table 6.1 – Characteristics of Peltier module, heatsinks & fans.

Specification	Characteristics
Peltier Module	TEC-12706 , 40mm × 40mm ×40mm
Cold side heat-sink	40mm × 60mm × 30mm (Aluminium)
Cold side fan	40mm × 40mm × 20mm
Hot side heat-sink	100mm ×100mm × 40mm (Aluminium)
Hot side fan	80 mm × 80mm × 30mm

CHAPTER 07

RESULT AND OBSERVATION

Chapter 7
RESULT AND OBSERVATION

7.1 Experimental Result

We had the goal to see the effect of the temperature difference by changing the voltage and see the effect of the Peltier effect with the time.

Four groups of different peltier voltage were set and studied-

Condition 1: 11V

Condition 2: 10V

Condition 3: 9V

Conditon 4: 8V

The observations were noted and described in graphical form.

Temperature vs Time Graph on Different Voltages-

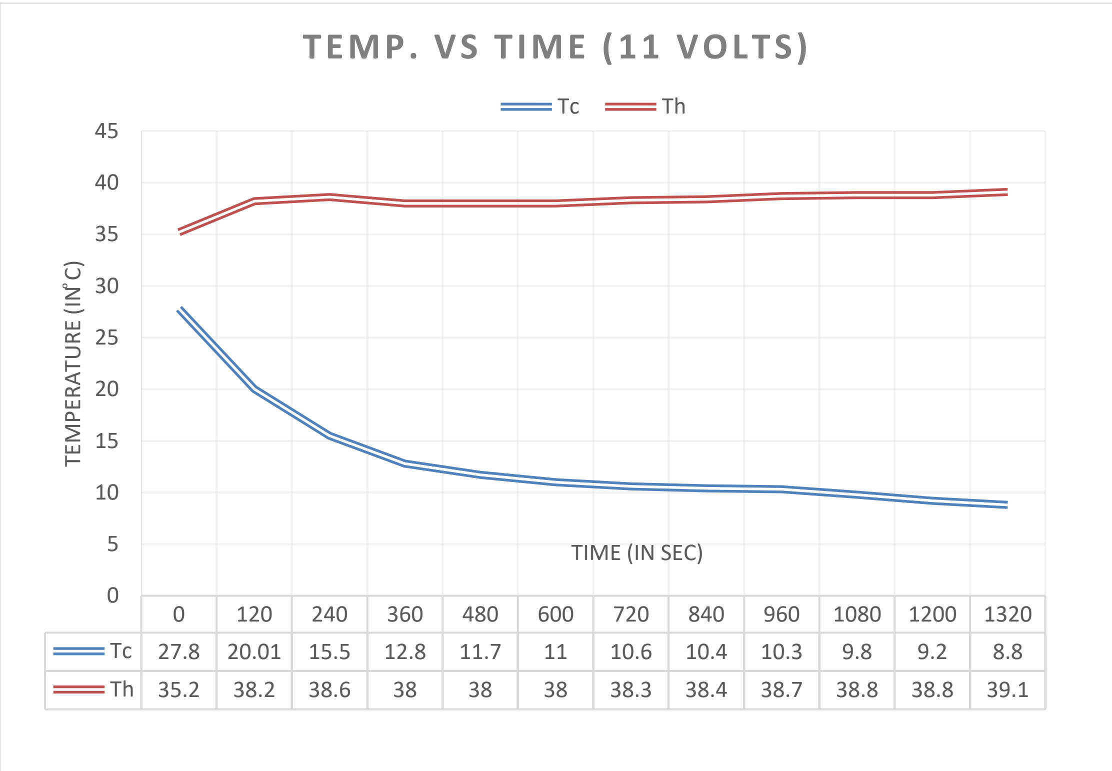


Figure 7.1 Temperature vs Time graph at 11 Volts

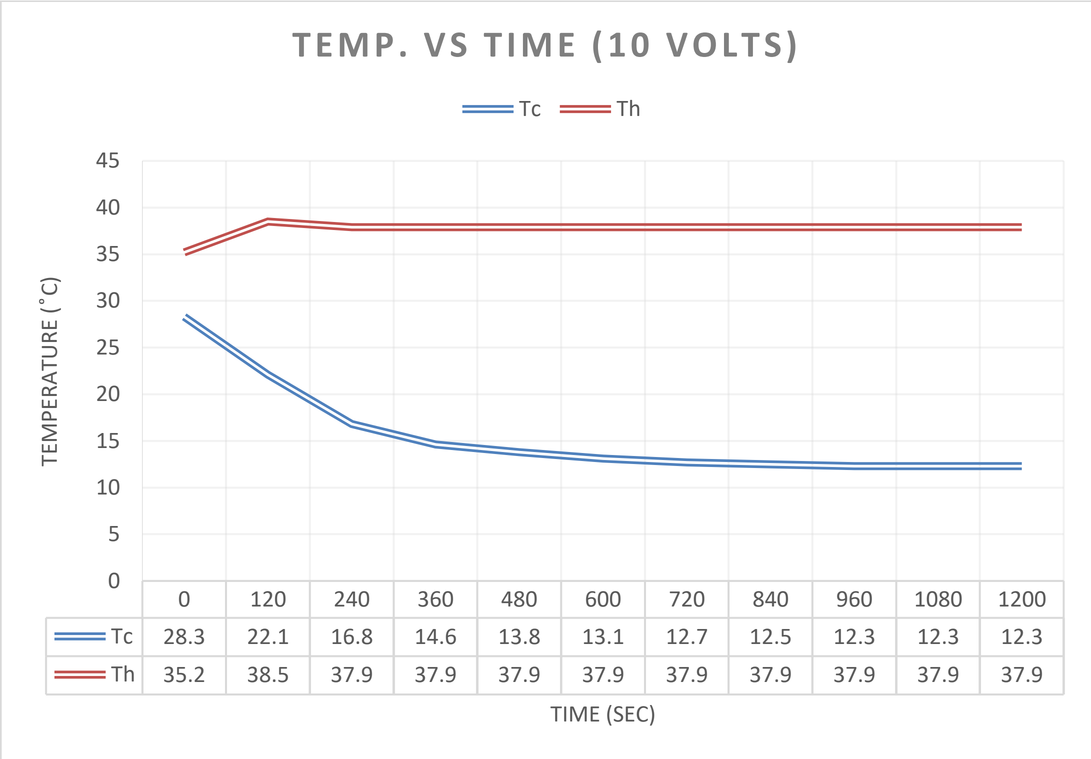


Figure 7.2 Temperature vs Time graph at 10 Volts

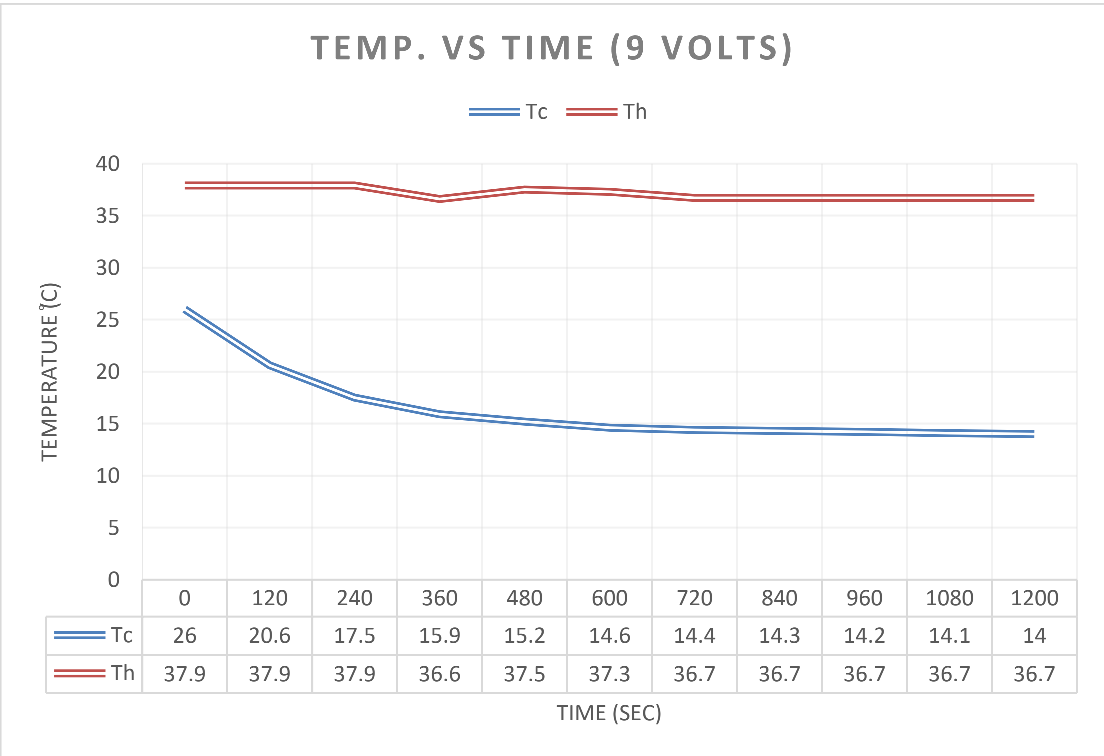


Figure 7.3 Temperature vs Time graph at 9 Volts

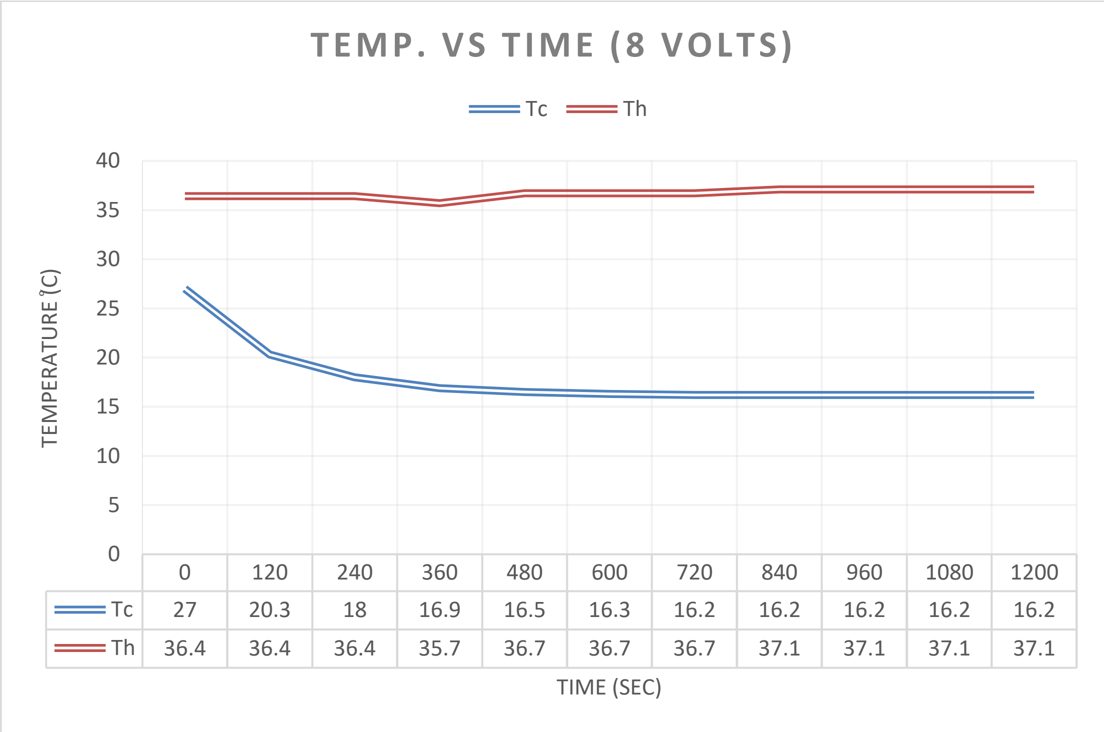


Figure 7.4 Temperature vs Time graph at 8 Volts

Fig 7.5 Lowest temperature reach at ambient temperature of 36°C

Fig 7.6 Lowest temperature reach at ambient temperature of 34°C

The testing of the prototype was done and observations were made. The graphs show that the temperature difference is also the function of the voltage with respect to the time. For higher voltage the value of temperature difference is also high and with the passage of time, temperature difference also increases.

The Lowest temperature reached was around **4.7˚C** with ambient temp of 36ºC**.**

The Lowest temperature reached was around **3.9˚C** with ambient temp of 34ºC**.**

The COP of system found to be **= 0.70**

Table – 7.1 Proposed specification of vaccine cooler

Particular	Specification
Voltage	**12 V**
Current	**3.5 A**
Power	**42 W**
Min. Temperature	**3.9ºC**
COP of system	**0.78**
Weight	**3 Kg**
Volume	**1.5 l**
Dimensions	**200mm * 150mm * 300mm**

CHAPTER 08

CONCLUSION

Chapter 8
CONCLUSION

From this project we can conclude that without the use of Compressor and the Refrigerant It is possible to cool the system. There are several different types of cooling devices available to remove the heat from industrial enclosures as well as medical enclosures, but as the technology advances, thermoelectric cooling is emerging as a truly viable method that can be advantageous in the handling of certain small-to-medium applications. The benefits that it provides including self-contained, solid-state construction that eliminates the need for refrigerants or connections to chilled water supplies, superior flexibility and reduced maintenance costs through higher reliability will increase as well. it can use to transport vaccines in last mile delivery, in ambulance for storing medical equipment, can use in remote area for storing medicines, etc.

Following are the conclusions made on basis of experimentation :

- Compared with natural convection heat transfer, cold side employs air-forced heat transfer is helpful for exchanging cooling. And cooling can easily spread inside the box. So, the temperature distribution of the box can be more uniform.
- A too high temperature of hot side will affect the working performance, even burn out semiconductor. So, heat dissipation of hot side is essential for the performance of refrigeration box.

We believe that thermoelectric cooling offers a number of advantages over traditional refrigeration methods as:

1. System has no moving parts.
2. No Freon's or other liquid or gaseous refrigerants required.
3. Compact size and light weighted.
4. Noiseless operation.
5. Eco-friendly C-pentane, CFC free insulation.
6. Reversing the direction of the current transforms the cooling unit into a heater.

<u>CHAPTER 09</u>

FUTURE SCOPE

Chapter 9
FUTURE SCOPE

- Peltier module-based refrigerator has a clearer approach of working so it can work as a good alternative to conventional refrigeration. It can be integrated with solar cells thus can help in switching to renewable source of energy. It will be a much cheaper source of refrigeration. It can be very helpful in rural and remote areas where electricity supply is not reliable. It can be used in military and mobile ambulances to preserve medicines.
- Peltier modules perform with low efficiency when compared to other systems like vapor compression or vapor absorption. Second, an effective heat sink is required to maintain the hotter side below air temperature in order to produce a temperature difference over the two faces of the module.
- LiPo battery can be used for better energy density than lead acid-based battery. In addition, the energy to weight density ratio of LiPo is better.

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