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Design and Fabrication of Refrigerator Using Peltier Cooling

Saikat Das [1], Himadri Sekhar De Mondal [1], Shuva Sundar Hazra [2], Arindam Halder [2], Riju Pramanik [2], Bapi Sarkar[2], Biswajit Biswas[3]
[1,2] Final Year B.Tech Students, Department of Electrical Engineering, Murshidabad College of Engineering & Technology, Murshidabad, India
[3] Assistant Professor, Department of Electrical Engineering, Murshidabad College of Engineering & Technology, Murshidabad, India
Email:saikatdas298@gmail.com[1], himadrimondal15@gmail.com[1], shuvahazra33@gmail.com[2], arindam2734@gmail.com[2], rijupramanik210@gmail.com[2], bapimcet@gmail.com[2], biswajit_35@yahoo.co.in[3]

Abstract- Refrigerator is a appliance for everyday use in both households and industries. Most of these works on vapor-compression cycle, which use CFC based refrigerants to cool the enclosed space. More or less all these refrigerants all global-warming agents. Thus we focused on searching an alternative and eco-friendly cooling system. Peltier cooling is one of them, It's free from refrigerants, portable, and can be used as alternative of conventional cooling. Our project aims to design and fabricate such a refrigeration system using peltier cooling. In this project, we successfully created a temperature difference of 9.2 °C using two peltier module in parallel. With some modifications, this system could find it's application in case of power failure, or where AC supply is not available to use conventional refrigeration.

Index Terms- Peltier cooling, refrigeration, Seebeck Effect.

1. INTRODUCTION

Refrigeration means removal of heat from a substance or space in order to bring it to a temperature lower than those of the natural surroundings. The work of heat transport is traditionally driven by mechanical work. Conventional refrigerators use vapor compression cycle to lower the temperature of an enclosed space by removing heat from that space and transferring it elsewhere. In Vapour-compression refrigeration or vapour-compression refrigeration system (VCRS) refrigerant undergoes phase changes. It is the most widely used method for refrigeration, air-conditioning of buildings and automobiles. The vapour-compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. All such systems have four components: a compressor, a condenser, a thermal expansion valve (also called a throttle valve or metering device), and an evaporator. Refrigerants are mostly from haloalkane family. These refrigerants were commonly used due to their superior stability and safety properties. They were not flammable at room temperature and atmospheric pressure. Unfortunately, chlorine and fluorine bearing refrigerants reach the upper atmosphere when they escape. In the stratosphere, CFCs break up due to UV radiation, releasing their chlorine free radicals. These chlorine free radicals act as catalysts in the breakdown of ozone through chain reactions. One CFC molecule can cause thousands of ozone molecules to break down. This causes severe damage to the ozone layer that shields the Earth's surface from the Sun's strong UV radiation, and has been shown to lead to increased rates of skin cancer. The chlorine will remain active as a catalyst until and unless it binds with another particle, forming a stable molecule. CFCs (R-11 and R-12), HCFCs (R-22) and HFCs (R-134A, R-410A) all have large global warming potential.

Since Peltier chip is a solid state device, and use no refrigerants, it has no harmful side-effects like vapour-compression cycle. Peltier based refrigerator is much more eco-friendly. It is portable due to its small size. This system offers an additional feature over conventional system, i.e. it can be used in any orientation, even in zero gravity, which makes it suitable for space applications. Thermoelectricity was discovered and developed in 1820-1920 in Western Europe, with much of work centered in Berlin. The first important discovery related to thermoelectricity occurred in 1821. German scientist Thomas Seebeck found that a circuit made from two dissimilar metals and junctions of the same kept at two different temperatures, produces thermoelectric force which is responsible for flow of the current through module. Now this invention is known as Seebeck effect. Later, in 1834, a French watchmaker and physicist, Jean Charles Athanase Peltier invented thermoelectric cooling effect also known as Peltier Effect. Peltier stated that electric current flows through two dissimilar metals would produce heating and cooling at the junctions.

2. LITERATURE REVIEW

In recent years, many researchers have worked on Peltier cooling, developing the system based on peltier cooling. Mayank Awasthi and K V Mali (2012) worked on designing of a thermoelectric refrigerator which was able to achieve a temperature of 15˚C with an ambient temperature of 32˚C. They achieved this result with a run time of 52 minutes with a 12V TE module (TEC-127-06L). Usable volume of the setup was 5.12 L with polyurethane foam of 20 mm thickness as insulation material [1]. Adithya Venugopal et al. (2014) studied on cost-effective refrigerator using thermoelectric effect and phase change materials. The objective of their project was to meet the demand for an economical, efficient and handy refrigerator for developing countries. Further, they used a PCM to maintain the temperature inside the cooling chamber for a long time even if the current through the thermoelectric cooler is stopped. They came up with a commercial prototype model at a very cheap price (roughly □ 2000 or $20) [2]. Ashok Kumar Yadav et.al. (2014) worked on a solar powered compressor less Air-conditioning system. They were able to cool 28.4L volume with their initial design. They used 6 sq. Inch solar panel with a bridge rectifier charging circuit for a battery to power their setup. Also there's an AC supply option as well. In addition, they also used cooling effect of Peltier heat pumps to extract water from the air in dehumidifiers [3]. Priyanka Jhavar et. al. (2015) studied on designing a thermoelectric refrigerator by using solar energy. An experimental prototype having a refrigeration space of 1 liter capacity was developed and four Peltier modules were used to cool the working volume under study. It is found that the temperature reduction of 11˚C without any heat load and 9˚C with 100 ml water kept inside were achieved in 30 minutes with an ambient temperature of 23˚C [4]. Swapnil B. Patond et al. (2015) worked on solar operated heating and cooling system. They utilized their design to cool a confined space and heat another space simultaneously. The system was consist of two separate chambers i.e. cooling chamber and heating chamber. It is found that the system can reduce temperature of water by 10˚C in 90 min of operation of the system. The system was also used to cool fruits (Oranges, 6˚C in first 20 min and additional 2˚C in 80min) and metal (Aluminium, Copper and Silver 9˚C in 50min). The heating chamber of the system also increases water temperature by 33.3˚C within 49 min of operation. Main benefit of their system is that it is a standalone system and can be installed in remote parts of the country where load-shading is a major problem [5]. Sagar D. Patil (2015) worked on methods to increase energy efficiency of domestic refrigerator using single stage thermoelectric module (TEM) and water cooled condenser. Cold side of the TEM was attached to the cooler chamber of a domestic fridge while the hot side of TEM was exposed to the environment. Seven thermocouples were placed at different section of the cooler chamber to measure temperature inside the system accurately. The system was tested for 6 hours. Total power input given to the test system was 150W. Their study concluded that the hybrid system of single stage TEM and water cooled condenser gives 15.72% better efficiency than that of domestic vapor-compression refrigeration system [6]. Sandip Kumar Singh and Arvind Kumar (2015) worked on construction of a thermoelectric refrigerator powered by solar panel. A temperature reduction of 12˚C without any heat load and 10˚C with 100 ml of water in refrigeration space at 24˚C ambient temperature in first 30 minutes were experimentally found at optimized operating conditions [7]. Pushkarny B.H et.al. (2016) worked on thermoelectric refrigeration with solar panels. They were able to achieve 11.7˚C reduction in temperature with their setup in 30 minutes runtime. The solar panel used to power the setup was 20W and consisted of 72 sub-cells [8]. Prasad Chavan et. al. (2016) researched on Performance Evolution of solar based Thermoelectric Refrigerator. The research was on designing a thermoelectric water cooler of working volume 4.5L.The system maintained a temperature between 15^0 C - 20^0 C throughout the test run. The thermoelectric module used was TEC 127-06L. They tested the experiment model at different ambient temperatures (21^0 C, 15^0 C, 32^0 C & 43^0 C) and a thermostat was used to control the temperature between the ranges of 15^0 C to 20^0 C [9]. Sujith G. et. al. (2016) worked on Design and Fabrication of a Thermoelectric Refrigerator with thermosiphon system. They designed an experimental system of 40 L working volume to achieve and maintain a temperature of 10˚C to 15˚C inside the refrigeration chamber. This system was designed to run for long time with alternative energy sources like battery or solar power. The outer walls of the refrigerator was made of mild steel and expanded polystyrene of 5cm thickness was used as inner wall materials. The system managed to maintain an average temperature of 13˚C inside the refrigeration chamber with ambient temperature of 33˚C throughout 450 min runtime. Analyses of the test result data showed an efficiency of 12.4% [10]. Abhijit Raju et al. (2016) designed and investigated an experimental model of refrigerator using six thermoelectric modules. It is found that the temperature reduction of 15^0c with 500 ml water kept inside refrigeration space could be achieved in 50 minutes with respect to 27^0c ambient temperature [11]. Nishan Shetty et. al. (2016) worked on Experimental analysis of solar powered thermoelectric refrigerator in the year of 2016. The refrigerator was made of 2 mm aluminum sheet with a working volume of 5L. They used 10 mm thick polystyrene foam (thermocol) for insulating the chamber to reduce heat conduction into the working space. Result shows the reduction of 10˚C temperature of the refrigerator with 250 ml water inside the working space with in 60 minute at an ambient temperature of 31˚C [12]. Nikhil S. Chougule et al. (2017) developed a thermoelectric refrigerator with working volume of one liter for their research work. The structure of the refrigerator was made of polyvinyl chloride with inner insulation layer of Polyurethane foam sheet to reduce heat losses. Thermoelectric module was used to reduce inside temperature of refrigeration working space. It is found that the developed system is able to reduce the temperature of 250 ml water from 30.6˚C to 9.6˚C i.e. 21˚C temperature reduction was achieved when the ambient temperature is 31˚C [13]. Palash Nakhate et.al. (2017) worked on Eco-friendly refrigerator using Peltier module. They proposed a system which should be able to cool a small volume to 6˚C to 8˚C.Microcontroller & DS18B20 Waterproof Digital Thermal Probe Sensor were used to preciously control temperature variation. They used 2mm aluminium sheet as heat sink [14].

All these studies clearly indicates that possibility of an alternate refrigeration system is just around the corners. We need Peltier cooling to replace existing VCRs, and get rid of haloalkane refrigerants. We focused our work on designing and fabricating an alternative cooling system using multiple Peltier modules in parallel to achieve a refrigeration system that could eventually replace conventional cooling systems.

3. METHODOLOGY

The core component of our project is Peltier module. The thermoelectric semiconductor material most often used in today's Peltier cooler module is an alloy of Bismuth Telluride that has been suitably doped to provide individual blocks or elements having distinct "N" and "P" characteristics. Thermoelectric materials most often are fabricated by either directional crystallization from a melt or pressed powder metallurgy. Each manufacturing method has its own particular advantage, but directionally grown materials are most common. In addition to Bismuth Telluride (Bi_2Te_3), there are other thermoelectric materials including Lead Telluride (PbTe), Silicon Germanium (SiGe), and Bismuth-Antimony (Bi-Sb) alloys that may be used in specific situations.

Crystalline Bismuth Telluride material has several characteristics that merit discussion. Due to the crystal structure, Bi_2Te_3 is highly anisotropic in nature. This results in the material's electrical resistivity being approximately four times greater parallel to the axis of crystal growth (C-axis) than in the perpendicular orientation. In addition, thermal conductivity is about two time's greater parallel to the C-axis than in the perpendicular direction. Since the anisotropic behavior of resistivity is greater than that of thermal conductivity, the maximum performance or Figure-of-Merit (will be discussed later) occurs in the parallel orientation. Because of this anisotropy, thermoelectric elements must be assembled into a cooling module so that the crystal growth axis is parallel to the length or height of each element and, therefore, perpendicular to the ceramic substrates. There is one other interesting characteristic of Bismuth Telluride that also is related to the material's crystal structure. Bi_2Te_3 crystals are made up of hexagonal layers of similar atoms.

While layers of Bismuth and Tellurium are held together by strong covalent bonds, weak van der Waals bonds link the adjoining [Te] layers. As a result, crystalline Bismuth Telluride cleaves readily along these [Te][Te] layers, with the behavior being very similar to that of Mica sheets. Fortunately, the cleavage planes generally run parallel to the C-axis and the material is quite strong when assembled into a thermoelectric cooling module.

Bismuth Telluride material, when produced by directional crystallization from a melt, typically is fabricated in ingot or boule form and then sliced into wafers of various thicknesses. After the wafer's surfaces have been properly prepared, the wafer is then diced into blocks that may be assembled into thermoelectric cooling modules. The blocks of Bismuth Telluride material, which usually are called elements or dice, also may be manufactured by a pressed powder metallurgy process. 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. The modules are considered to be highly reliable components due to their solid state construction. For most application they will provide long, trouble free service.

The p-type semiconductor is doped with certain atoms that have fewer electrons than necessary to complete the atomic bonds within the crystal lattice .When a voltage is applied, there is a tendency for conduction electrons to complete the atomic bonds. When conduction electrons do this, they leave "holes" which essentially are atoms within the crystal lattice that now have local positive charges .Electrons are then continually dropping in and being bumped out of the holes and moving on to the next available hole. In effect, it is the holes that are acting as the electrical carriers.

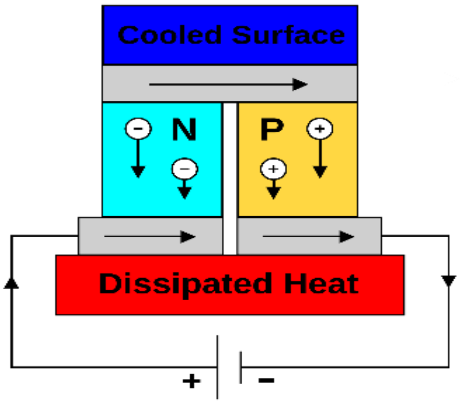

Fig 1: SCHEMATIC DIAGRAM OF PELTIER COOLING

Now, electrons move much more easily in the copper conductors but not so easily in the semiconductors. When electrons level the p-type and enter into the copper on the cold-side holes are created in the p-type as the electrons jump out to a higher energy level to match the energy level of the electrons already moving in the copper. The extra energy to create these holes comes by absorbing heat. Meanwhile the newly created holes travel downwards to the copper on the hot side. Electrons from the hot – side copper move into the p-type and drop into the holes, releasing the excess energy in the form of heat.

The n-type semiconductor is doped with atoms that provide more electrons than necessary to complete the atomic bonds within the crystal lattice. When a voltage is applied, these extra electrons are easily moved in to the conduction band. However, additional energy is required to get the n-type electrons to match the energy level of the incoming electrons from the cold-side copper. The extra energy comes by absorbing heat. Finally when the electrons leave the hot-side of the n-type, they once again can move freely in the copper. They drop down to a lower energy level, and release heat in the process.

4. EXPERIMENTAL SETUP

The refrigeration chamber is made of plywood. The shape of the chamber is rectangular cube with a working volume of 6.2L. For insulation, Expanded Styrofoam is used and the inner wall of chamber is covered with fiber pane. To eliminate any air gap between outer and inner layer of the chamber, PU (polyurethane) foam is used. Two Peltier modules are mounted on the top side of the chamber. Heatsink with CPU fans are connected on the both side of Peltier module for both units. The whole setup runs on 12V DC supply. The details of used hardware are listed below.

Fig 2: REFRIGERATION CHAMBER

TABLE I

Refrigeration Chamber	
Length (cm)	31
Width (cm)	31
Height (cm)	33

TABLE III

Construction & Insulation Materials		
Material	Thickness(cm)	Thermal Conductivity (W/m-K)
Plywood	1.25	0.13
Expanded Styrofoam	5.1	0.033
Fiber Pane	0.3	0.288

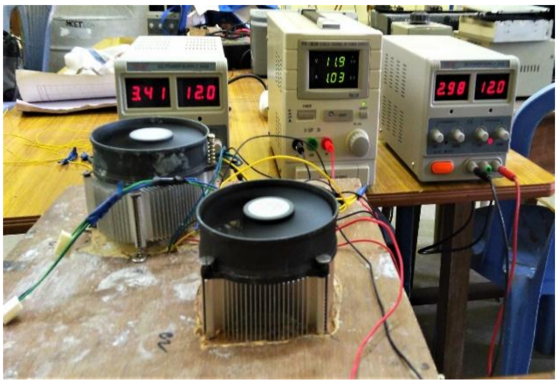

Fig 3: EXPERIMENT SETUP

5. RESULT

A few assumptions are made while calculating the result. It is assumed there is no air exchange with the air external to the enclosure, no solar loading, and no ongoing condensation is occurring inside the enclosure (which will increase the heat load). We have varied the working volume several times and experimented with different power inputs. Our aim was to find a relation between working volume and power input for our setup.

We successfully decreased 9.2˚C temperature with a working volume of 6.2L with power input of 82 W with a runtime of 50 min.

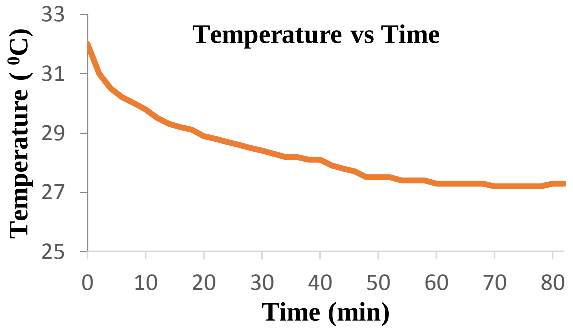

Fig 4: TEST RUN 1 FOR VOLUME OF 11.36L

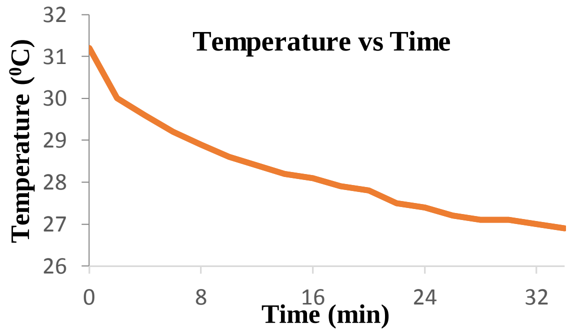

Fig 5: TEST RUN 2 FOR VOLUME OF 10.32L

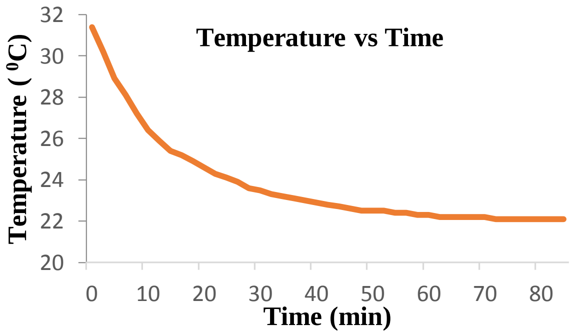

Fig 6: TEST RUN 3 FOR VOLUME OF 6.2L

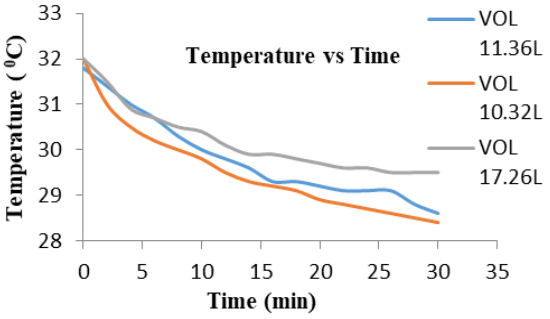

Fig 7: TEMPERATURE REDUCTION CHART FOR VARIOUS VOLUME

6. CONCLUSION

Our objective was to create a refrigeration system which is eco-friendly and could replace existing vapor-compression cycle refrigeration system. Though our project is still far from that target, still we managed to lower the temperature enough to use this system as alternative in case of power failure, since it could be operated with batteries or even with solar panel. We observed different temperature reduction for different runtime with different volume. We are looking forward to improve and modify our refrigerator further to achieve even lower temperature. Designing and working with heat sink was the most important part of our experiment. With improved heat exchanger design, system efficiency could drastically improve.

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