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Design of Low Cost Refrigeration System using Peltier

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Abstract: *The continuous development of science and technology has led to innovative refrigeration methods that are energy-efficient, compact, and environmentally friendly. This project focuses on the design and development of a low-cost refrigeration system using the Peltier effect. Unlike conventional vapor compression systems, the proposed system employs a thermoelectric module (Peltier module), eliminating the need for compressors and harmful refrigerants.*

When electric current passes through the thermoelectric module, a temperature difference is created, producing a hot side and a cold side. This principle is utilized to achieve the required cooling effect. The system is designed to be lightweight, portable, and suitable for applications where conventional refrigeration is impractical. The entire setup is fabricated and experimentally analyzed to evaluate its cooling performance, efficiency, and cost-effectiveness.

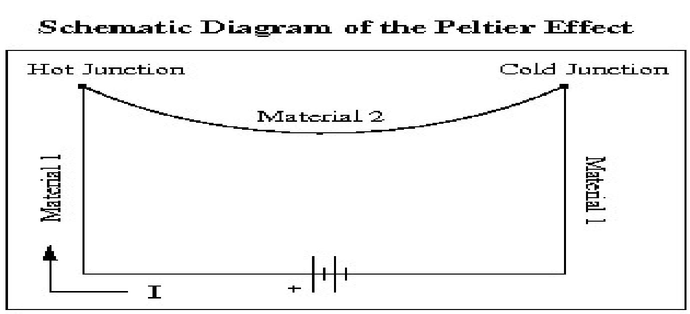
The results indicate that the developed refrigeration system is capable of maintaining a stable temperature suitable for preserving medicines and food items, particularly during travel and in remote or emergency conditions. Due to its low cost, portability, and eco-friendly operation, the proposed system presents a viable alternative to traditional refrigeration systems for small-scale cooling applications..

Keywords: Thermoelectric module (TEM), Peltier Effect, thermal energy, compressor, semiconductor etc

I. INTRODUCTION

Refrigeration is essential for preserving food, medicines, and other temperature-sensitive materials. Conventional refrigeration systems use compressors and refrigerants, which are bulky, costly, and harmful to the environment. To overcome these limitations, thermoelectric refrigeration using the Peltier effect offers a compact and eco-friendly alternative.

A Peltier module produces a cooling effect when electric current passes through it, creating hot and cold sides without any moving parts or refrigerants. This project focuses on designing a low-cost refrigeration system using a Peltier module that is lightweight, portable, and suitable for small-scale applications such as medicine preservation and travel use.



(Fig 1.1. Peltier Effect diagram)

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1.1 Advantages of Thermoelectric Refrigerators

No Moving Parts: A TE module works electrically without any moving parts so they are virtually maintenance free.

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 [5]. This feature eliminates the necessity of providing separate heating and cooling functions within a given system.

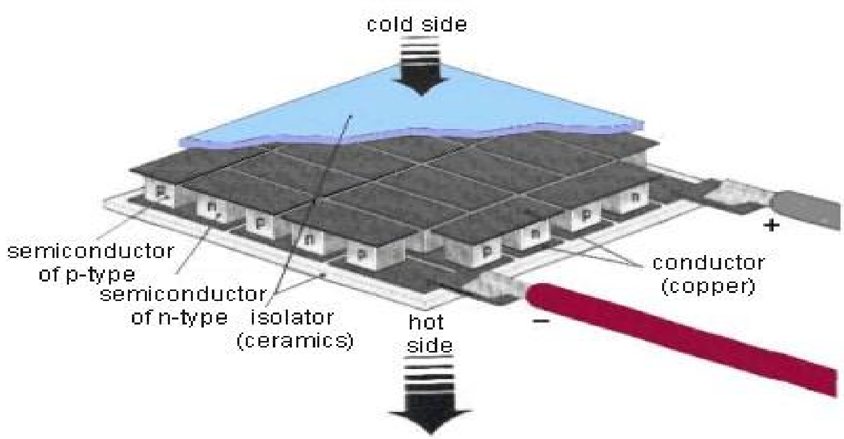
Electrically Quiet Operation: Unlike a mechanical refrigeration system, TE modules generate virtually no electrical noise and can be used in conjunction with sensitive electronic sensors. They are also acoustically silent.

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 [11].

II. SET-UP DESCRIPTION

For the construction of the Thermoelectric Refrigerator four main components are used, which are as follows

2.1 Peltier Module: - The method of thermoelectric cooling (using the Peltier effect) is useful because it can cool an object without any moving pieces or other complex machinery that isolates the cooler from its ambient surroundings. The devices that are constructed to take advantage of this phenomenon are known as Peltier elements, or thermoelectric coolers (TECs). The most common combination of materials in the thermocouples of Peltier elements (TECs) are the two semiconductors Bismuth and Tellurid. The semiconductor cubes with extra free electrons (and thus carry mainly negative charge) are known as N-type semiconductors, while those with few free electrons (and carry mainly positive charge) are P-type semiconductors. The pairs of P and N semiconductor cubes are set up and connected in an array so that the pairs have an electrical series connection, but a thermal parallel connection. When a current is applied to this system (the TEC), the way the current flows through the semiconductors induces a temperature difference, and causes the heat-sink side of the Peltier element to heat up, and the cold side to cool (or cooling whatever is in thermal contact with that side).



(Fig 2.1. A Peltier Module)

2.2 Heat Sink: - Rather than being a heat absorber that consumes heat by magic, a thermoelectric cooler is a heat pump which moves heat from one location to another. When electric power is applied to a TE module, one face becomes cold while the other is heated. In accordance with the laws of thermodynamics, heat from the (warmer) area being cooled will pass from the cold face to the hot face...

2.3 DC Power Supply: - The Peltier Module requires DC power supply for its working, hence a power driver is used to deliver constant current to the cooler at 12V, 10Amp.

2.4 Insulated Case: - Thermal insulation is defined as a material or combination of materials which on application retards the flow of heat and adapted to any size, shape and surface. Thus, the insulation is the outcome of performing the process to thermally isolate the system using insulating materials to reduce the heat transfer rate drastically between

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the system and the adjacent body or the environment. As we know 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.

III. BASIC CONCEPTS

The working of the THERMOELECTRIC REFRIGERATOR is based on various theories or concepts. These theories are related to mainly heat transfer and refrigeration. Electrical concepts such as semiconductors and their doping is also a significant part of the project. Following are the theories involved in the construction -

- The Peltier Theory.
- Semiconductors with doping.
- Heat transfer through Heat Sink.
- Forced convection.

A brief description of each element listed above is given below.

3.1 Peltier Theory: - Thermoelectric coolers operate according to the Peltier effect. The effect creates a temperature difference by transferring heat between two electrical junctions. A voltage is applied across joined conductors to create an electric current. When the current flows through the junctions of the two conductors, heat is removed at one junction and cooling occurs. Heat is deposited at the other junction.

The main application of the Peltier effect is cooling. However the Peltier effect can also be used for heating or control of temperature. In every case, a DC voltage is required.

Thermoelectric coolers act as a solid-state heat pump. Each features an array of alternating n- and p- type semiconductors. The semiconductors of different type have complementary Peltier coefficients. The array of elements is soldered between two ceramic plates, electrically in series and thermally in parallel. Solid solutions of bismuth telluride, antimony telluride, and bismuth selenide are the preferred materials for Peltier effect devices because they provide the best performance from 180 to 400 K and can be made both ntype and p-type.

Cooling occurs when a current passes through one or more pairs of elements from n- to p-type; there is a decrease in temperature at the junction ("cold side"), resulting in the absorption of heat from the environment. The heat is carried along the elements by electron transport and released on the opposite ("hot") side as the electrons move from a high- to low-energy state.

The Peltier heat absorption is given by Q = P (Peltier Coefficient) I (current) t (time). A single stage thermoelectric cooler can produce a maximum temperature difference of about 70 degrees Celsius. Thermoelectric Cooler will chill electronics as much as 2 degrees Celsius below current market offerings.

(Fig 3.1. The Peltier module used for the project)

3.2 Semiconductors with Doping: - Doping is the process of introducing impurity atoms, called dopants, into semiconductor materials during their production. The presence of dopants in semiconductor materials increases the number of available charge carriers, thus altering the material's electrical properties. Doped semiconductors are semiconductors which contain impurities, foreign atoms which are incorporated into the crystal structure of the semiconductor. These impurities can either be unintentional due to lack of control during the growth of the semiconductor or they can be added on purpose to provide free carriers in the semiconductor. There are two types of doping processes, n-doping and p-doping, which depend on the dopants that are introduced into the semiconductor material.

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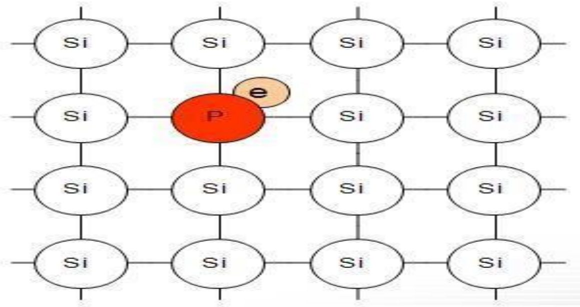
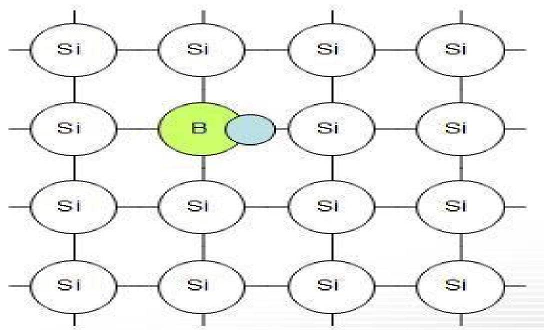
N-Type: N doped semiconductors have an abundant number of extra electrons to use as charge carriers. Normally, a group IV material (like Si) with 4 covalent bonds (4 valence electrons) is bonded with 4 other Si. To produce an N type semiconductor, Si material is doped with a Group V metal (P or as) having 5 valence electrons, so that an additional electron on the Group V metal is free to move and are the charge carriers.



(Fig.3.2. N-Type of Doping)

P-Type: For P type semiconductors, the dopants are Group III (In, B) which have 3 valence electrons, these materials need an extra electron for bonding which creates holes . P doped semiconductors are positive charge carriers. There's an appearance that a hole is moving when there is a current applied because an electron moves to fill a hole, creating a new hole where the electron was originally. Holes and electrons move in opposite directions.



(Fig 3.3. P-Type of Doping)

3.3 Heat Transfer through Heat Sink: - A heat sink is an electronic device made of good thermal conducting material and usually attached to an electronic device to dissipate the unwanted heat. It is used to cool the circuit components by dissipating the excess heat to prevent overheating, premature failure, and improve the reliability and performance of the components.

Thermal conduction occurs whenever two objects at different temperatures are in contact. This involves the collisions between the fast molecules of the hotter object with the slow moving molecules of the colder object. This leads to the energy transfer from the hot object to the cooler object. A heat sink thus transfers the heat from the high temperature component such as a transistor to the low temperature medium such as air or any other suitable medium through conduction and then convection.

3.4 Forced Convection: - Forced convection is a special type of heat transfer in which fluids are forced to move, in order to increase the heat transfer. This forcing can be done with a fan, a pump, suction device, or other. This difference in density makes hotter material naturally end up on top of cooler material due to the higher buoyancy of the hotter material. Forced convection creates a more uniform and therefore comfortable temperature throughout the entire heat sink.

3.5 Specifications of Refrigerator

For Peltier module -

Model number: TEC1-12706, Voltage: 12V, U max (V): 15.4V, Imax (A): 6A, Q Max (W): 92W, internal resistance: 1.98 Ohm +/- 10%, Power Cord: 150mm, HS Code: 854150, Type: Cooling Cells, Usage: Refrigerator/Warmer, Dimensions: 40*40*3.9mm.

For power -

Source: 12 volts DC power unit, Module: 12 volts, Fans: 7 amps, Temperature indicator: 12 volts, Minimum power required is 12 volts at 6 amp.

Electrical data -

Power source: 12volts DC power unit, Rated supply: 12volts 10 amps.

Cooling fan and unit -

Minimum speed: 1000RPM, Moderate speed: 1500RPM, Maximum speed: 1900RPM,
Dimensions: 122.5*116*80.6mm.

Refrigerator dimensions - Length: 25cm, Breadth: 24cm, Height: 55cm

Cooling space dimensions - Length: 12cm, Breadth: 18cm, Height: 25cm

Materials used for making-

Plywood of 10mm thickness is used for making main frame. Thermocol is used for making the inside of the refrigerator. Aluminium foil is used on top of thermocol to increase the cooling effect and insulation.

IV. ASSEMBLY OF REFRIGERATOR

4.1 Assembly for Heat Sink and Fan

The Heat Sink is fitted with the Fan via several screws. Heat sink also has a set of copper pipes going through it to maximize heat transfer from the sink to the air.

4.2 Peltier Module Assembly

The Peltier module is attached on top of the Heat Sink and fan through a thermal paste which does not causes any resistance to the heat, when it flows from the module to Heat Sink unit.

4.3 Final Refrigerator Assembly

Peltier module with Heat Sink is connected on top of the Frame or main body of refrigerator to ensure that cold air from the module is evenly distributed in all directions inside the refrigerator compartment. The frame is made up of plywood of 10mm. The Peltier module with the Heat sink is fitted on the upper portion of the frame. A digital thermometer is attached at the upper portion of the frame to display the inside temperature of the refrigerator.

4.4 Inside of the Refrigerator

The inside of the refrigerator is made up of thermocol covered with the aluminium foil to increase the insulation. It also helps in increasing the cooling effect inside the compartment.

V. CONCLUSION

During construction of the device several minor changes were made to the design. Each of these changes we feel was justified as they made for easier construction while maintaining the performance of the device with respect to the project goals. The device was discovered to have ample precision and total heat transfer capabilities while meeting its accuracy requirement. It can be used for cooling small beverages, drinking water, medicines etc.

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