COOLING WITH ELECTRICITY: BUILDING A THERMOELECTRIC REFRIGERATOR

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Abstract: This research study presents the design and construction of a Peltier-based thermoelectric refrigerator. To generate the temperature difference between the thermoelectric module the device utilizes See back effect. The refrigerator was designed to have a compact size, low power consumption, and high cooling efficiency. The design, production, and analysis of a thermoelectric refrigerator are the subjects of this project. The design and fabrication of this thermoelectric refrigerator provide a potential solution for small-scale cooling applications with low power requirements, such as cooling electronic devices, medical equipment, and food storage.

Keywords: Peltier coolers, CFCs, Thermoelectric Modules, Heat Sinks, Thermal Analysis, and Refrigeration.

I. INTRODUCTION:

In order to drop a space's temperature below the ambient level, heat must be removed from it through the process of refrigeration. The "Peltier cooling module," as opposed to other extensively used traditional cooling methods like the "vapour compression cycle" or the "vapour absorption cycle," which uses thermoelectric refrigeration, intends to deliver cooling by exploiting thermoelectric effects. When two junctions and two different metals are used to construct the circuit then current will flow between the joints or the circuit The see back effect is a name for this occurrence. French watchmaker and amateur scientist C. Peltier discovered See backs opposite effect. He realized that a heat pump may be created by joining metals that are different. The increased need for refrigeration across a variety of industries resulted in increased power generation and, as a result, increased global emissions of CO2, a gas that contributes to climate change and global warming. A brand-new alternative technique is thermoelectric refrigeration.

To produce cold and hot surfaces the thermoelectric modules are constructed from semiconductor materials that are thermally and electrically coupled in parallel. They are less efficient than a vapour compression system but they are more cost-effective, environmentally friendly, and quieter to operate. Electrical energy is applied to a pair of fixed junctions in a thermoelectric module, resulting in the coldening of one junction and the heating of the other. The benefits of thermoelectric cooling, a type of solid-state refrigeration, include portability and robustness. It doesn't use any fluids, has only a few fans that move, and doesn't require the size of mechanical compressors and massive pipes found in vapor-cycle cooling systems. In some circumstances, its durability makes thermoelectric cooling preferable to traditional refrigeration. Conventional refrigeration cannot be used because to the design's portability, small size, and weight constraints.

II. LITERATURE REVIEW :

[1]The paper tells us that, in today's refrigerators, a compressor and coolant serve as the working fluids for the transfer of heat. As the coolant being utilized expands and contracts and changes states from liquid to vapor to vice versa, thermal energy is received and released. The thermoelectric refrigerator powered by solar energy, sometimes referred to as the Peltier refrigerator, has a number of advantages over traditional systems. As there are no moving parts and only solid-state components, the system is reliable and quieter.

Ozone-depleting chlorofluorocarbons, which have a poor impact on the environment, are not used. When operational, they take up substantially less space than traditional systems. Peltier coolers are used to regulate the temperature (by 7 °C). These coolers are less efficient than compressor-based refrigerators. As a result, they are utilized in particular applications due to their special benefits. Yet, some expansive uses have been taken into account. In situations where tiny size is required and the cooling demand is modest, such as cooling electronic components, Peltier coolers are typically employed. The primary goal of this paper is to create a thermoelectric refrigerator prototype that uses the Peltier effect to perform temperature control between 5 and 25 degrees Celsius and provide refrigeration in off-grid locations without access to power.

[2] A scholarly article discussed the creation of a miniature Peltier thermoelectric cooler that measured 20 x 26 x 18 mm. The cooler's design consisted of a Peltier thermoelectric cell sandwiched between two heat sinks, one on the interior and one on the exterior of the cooler box. This configuration allowed the generated heat to be dissipated. When the Peltier thermoelectric cell was connected to an external power source, it produced a cooling effect that removed heat from inside the refrigerator and released it to the surrounding environment. The experimental data from this study verified the theoretical thermal resistance model. According to the results, the Peltier cooler achieved COP values above 0.5, indicating a higher output than previous experiments. With

the dissipation of 25W of heat, the cooler reduced the temperature inside the box to 18.5 °C from the ambient air. The validated theoretical model created in this research can be used in the future to predict essential design parameters such as heat sink type and size, cooling temperature, and cooler performance, including the coefficient of performance (COP).

[3] The paper tells us advancements in science and technology have led to the development of thermoelectric cooling systems, including Peltier heat pumps and solid-state refrigerators, which have found widespread use in cooling applications and as temperature controllers due to their low maintenance requirements and lack of moving parts. Thermoelectric refrigeration is a promising alternative to traditional refrigeration methods, utilizing the Peltier effect to generate cooling effects in refrigeration compartments. This research paper describes the design and fabrication of a thermoelectric refrigerator that utilizes 12 Peltier modules, 5 12V DC fans, and separate fridge and freezer compartments. The study evaluates the refrigerator's performance by analysing the coefficient of performance of the Peltier modules and the temperature achieved by the compartments after two hours of use. The results show that the Peltier modules used in the refrigerator had a coefficient of performance of 81.85%, demonstrating the efficiency of thermoelectric refrigeration. The fridge and freezer compartments were able to achieve temperatures of 6.9 °C and −5.3 °C respectively, indicating the potential of thermoelectric refrigeration for practical cooling applications. This study provides important insights into the design and performance of thermoelectric refrigeration systems that can inform future research and development in this field.

[4] The article proposes a novel refrigeration system that uses Peltier modules instead of traditional mechanical components to eliminate vibrations, noise, and pollution from hazardous refrigerants. Peltier modules are a lightweight, compact, and highly reliable alternative to traditional refrigeration systems. The article finds that using water blocks with Peltier modules is more effective than using aluminium heat sinks. The refrigeration system employs a three-layer design consisting of an iron casing, pharmocol insulation, and aluminium cabin to act as a cooling chamber. The study emphasizes the cost-effectiveness, cleanliness, and environmental friendliness of this system, which makes it suitable for preserving food, medical applications, and other items. Additionally, the system is portable, making it highly convenient. The article offers valuable insights into the design and operation of this innovative refrigeration system, which can aid future research and development in this area.

[5] The paper provides an insightful overview of the increasing interest in thermoelectric technology and its potential applications in energy management. It provides a detailed explanation of the principles of thermoelectricity and discusses various materials currently being used and developed for thermoelectric power production, such as thermoelectric generators and thermoelectric cooling systems. The paper also presents various optimization models for thermoelectric applications, including non-equilibrium thermodynamics and finite time thermodynamics, and introduces several topical applications and energy resources that can be utilized with thermoelectric technology.

The paper's main objective is to provide a comprehensive understanding of thermoelectric technology and its potential applications in the energy sector. This makes it a valuable resource for policymakers and researchers interested in improving energy system performance and exploring alternative sources of energy. Overall, the paper offers an excellent overview of the field of thermoelectric technology and its potential applications, making it a valuable reference for future research in this area.

III. THERMOELECTRIC REFRIGERATION:

- In order to generate the temperature gradient between different materials Peltier effect is used, which facilitates the passage of heat
- This effect is commonly used for cooling small electrical parts, instruments, and portable coolers for camping.
- Applying a DC voltage to a thermoelectric module causes it to absorb heat on one side and release it on the other side, resulting in a cold face and a warm face.
- If the two junctions of the module remain at different temperatures, a voltage difference is produced across the module, and electrical power is generated.

IV. BASIC PRINCIPLES OF THERMOELECTRIC:

The research requires careful examination of the fundamental concepts that underpin thermoelectricity. The See back, Peltier, Thomson, Joule, and Fourier effects are examples of effects.

1. See back effect: Thermoelectric power supply generators are based on the See back effect, which is based on voltage generation along a conductor subjected to a temperature gradient. A conductor experiences an electromotive force when it is exposed to a temperature gradient. The difference between both the cold and hot sides voltage gives us an idea about the temperature difference between them.

2. Peltier effect: All thermoelectric cooling applications primarily rely on the Peltier effect. It is in charge of heat absorption and heat removal. This theory proposes that the heat absorption or emission at the junction of two conductors is determined by the direction of the electric current flowing through them.

3. The Thomson effect governs how much a material cools and how much it heats when it is exposed to a temperature

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gradient while carrying a current. The theory suggests that when an electric current flows through a conductor with a temperature difference along its length, the conductor will either absorb or release heat.

V. MODULES OF THERMOELECTRIC COOLING

Peltier was discovered very much earlier but its use has been found recently. In optoelectronic devices such as photodetectors, CCDs, diode lasers, solid-state pumped lasers, and similar devices the Thermoelectric solutions are being increasingly employed.

The P-type and N-type semiconductor thermos element pairs that make up the thermoelectric module's thermocouple are thermally and electrically coupled in parallel and series, respectively. The solid state design of the modules is thought to make them extremely dependable. For the majority of applications, they will offer a lengthy, problem-free service.

The module is provided an electrical current source for cooling, which causes heat to move from one side to the other and make the module colder on one side and hotter on the other.

Thermoelectric refrigerators work based on the principles of the Peltier effect, which is also known as the thermoelectric effect or Peltier-See back effect. This effect involves the direct conversion of electric voltage to temperature differences and vice versa. While the Peltier-See back and Thomson effects can be reversed, the laws of thermodynamics prohibit joule heating from doing so.

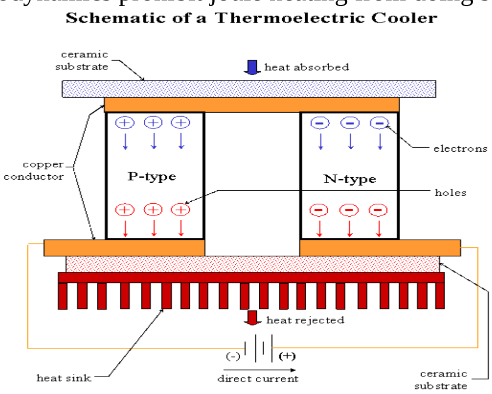

Fig. 1. Module working

VI. METHOD OF HEAT TRANSPORT:

• Compared to copper conductors, semiconductors do not allow electrons to travel as freely.
• Electrons need to occupy a "hole" or an empty space where an electron is absent in order to move through the hot side of the p-type material, which is situated adjacent to the copper conductor
• Heat is absorbed due to their higher energy level when electrons move from the p-type to the cold side of the copper conductor, As electrons leave the copper and enter the hot side of the p-type material, they emit heat by occupying a hole and transitioning to a lower energy state.
• Electrons need to increase their energy level to move through the n-type semiconductor as they transition from the p-type. Once they reach the cold side of the n-type material, they can move through the copper easily.
• Electrons absorb heat and complete the process as they leave the hot side of the n-type semiconductor and pass through the copper conductor unobstructed.
• To enhance heat transfer, p-type or n-type thermoelectric components should be connected in parallel; however, this can result in energy loss and heat generation
• The device's requirements exceed the limits of commercial applications. The thermal conductivity decreases due to thermal shorting when the semiconductors are connected in parallel, although the TE components can be connected in series.
• The configuration that offers the highest efficiency involves connecting a p-type and an n-type thermoelectric component in an electrical series, while maintaining a thermal parallel configuration.
• In order to prevent electrical short circuits between the heat source and the thermoelectric module, it is necessary to insert an insulator between the conductor and the heat source. To achieve the best possible results, it is recommended to position the hot side of the module facing the heat sink, and the cold side facing the heat source.
• In addition to its electrical insulating properties, the insulator material should have a high thermal conductivity in order to minimize the temperature difference between the conductor and the heat source.
• For this reason, ceramics like alumina are typically employed. 254 thermoelectric devices of the alternating p and n types are used in the most typical devices. The gadgets can run at 4-5 amps and 12-16 volts. These standards are considerably more applicable to operations in the real world.

VII. PROJECT OBJECTIVE:

The primary goal of the proposed work is to create a refrigeration system with a 6L cooling chamber. Designing a system that can keep the materials' temperature between 5°C and 20°C is essential. When two distinct kinds of materials are in contact with one another, the Peltier effect creates a heat fluxA.

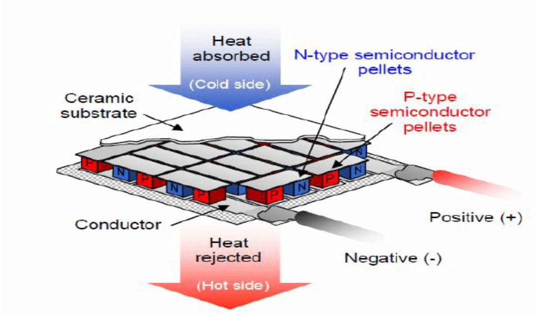

Fig. 2. Thermoelectric module

Devices like Peltier heater, cooler, and heat pump use electricity to make temperature differences so that heat gets transferred from one direction to another.

VIII. GEOMETRY

The device's design is restricted by specific objectives, To meet the above requirements, a rectangular box with two walls separated by insulation is often used, and its dimensions are chosen accordingly. Sizes of the top and bottom panels are 16 x 23 cm. Dimensions for the vertical side panel: 16 x 30 cm. Sizes of the front and back panels are 23 x 30 cm.

IX. DESIGN PROCEDURE :

Understanding the thermal load is one of the most important steps in developing a thermoelectric cooling system. With this crucial information, we can select the ideal heat exchangers or TE devices for the task. The capacity of each thermoelectric cooling system to move heat is different. To attain the desired performance goals, it is crucial to determine the quantity of heat that must be eliminated from the thermal load. The module is chosen based on the heat amount that must be removed before the hot side of the module can be cooled by a thermosiphon system.

X. FABRICATION AND ASSEMBLY:

Fig. 3. Front view of project

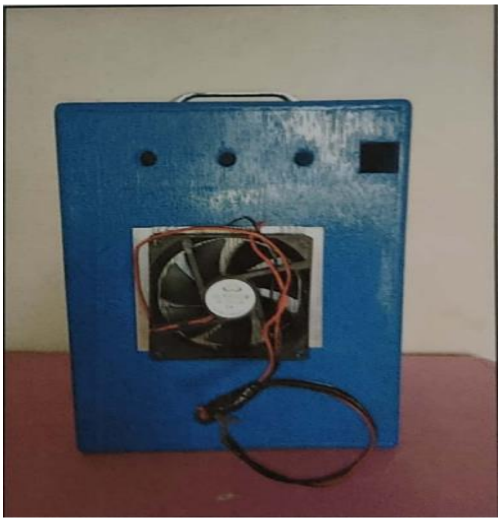

Fig. 4. Back view of project

9.1 THERMOELECTRIC MODULE

Thermoelectric modules, also referred to as Peltier modules, function as solid-state heat pumps that utilize the Peltier effect. The unique design of thermoelectric modules enables them to transfer heat from a cooler area to a warmer area, effectively rendering them as heat-pumping thermoelectric devices

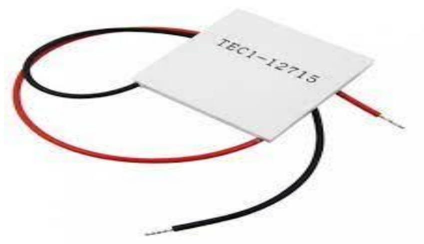

Fig. 5. Peltier module

9.2 HEAT SINK

Fig. 6. Heat sink

The results of the analysis that came before are utilized to determine the system's overall viability. Our assumption regarding the 15°C temperature rise across the heat sink must be clarified, as the efficiency of the heat sink has a significant impact on the thermoelectric module's ability to effectively pump heat. To ensure effective heat transfer, the hot side of the module needs to be connected to a well-designed and efficient heat sink.

9.3 TEMPERATURE INDICATOR

Fig. 7. Temperature indicator

A tool for measuring the temperature within a refrigerator's chamber is the temperature indicator. It contains a probe that is installed within the chamber of the refrigerator; it senses the temperature there and sends that information to the output display To reduce thermal losses from the cabin, the upper door panel is typically fastened using spot welding, and rubber beading is installed to prevent heat from escaping through the sides of the door panel.

9.4 HEAT SINK FAN

The temperature of the refrigerator is lowered from 33.1 °C to 13.2 °C in around 15 minutes using a heat sink fan. This is essential because heat transmission can result in the heat sink itself getting warm.

9.5 SMPS:

Fig. 8. SMPS

A type of electronic power supply called a switched-mode power supply (SMPS), also referred to as a switched power supply, switcher, switch-mode power supply, or switched power supply, utilizes a switching regulator to alter voltage and current characteristics in order to distribute power to DC loads, such as personal computers, from either a DC or AC source, usually the mains power. Unlike linear power supplies, the pass transistor in an SMPS spends minimal time in high dissipation transitions and alternates between fully on and fully off states with low dissipation, resulting in reduced wasted energy. In theory, there is no power loss in an ideal SMPS. The duty cycle, or ratio of on-to-off time, can be adjusted to control voltage.

XI. CALCULATION :

To determine the Coefficient of Performance (COP) for refrigeration using a Peltier module, we require knowledge of the electrical power input and cooling power output. The cooling power can be calculated using the following formula:

$$\text{Cooling power} = (Thot - Tcold)\ x\ I,$$

When an electric current I passes through the Peltier module, Thot and Tcold denote the temperatures on the hot and cold sides, respectively. Given that the temperature difference is 10°C, the hot side temperature would be

$$Thot = Tcold + 10 = Tcold + \Delta T.$$

Assuming an efficiency of 50%, the input electrical power would be:

Input power = $V\ x\ I$ = 12V x 5A = 60W

Therefore, the cooling power would be:

Cooling power = (Tcold + 10 - Tcold) x 5A = 50W

The COP can now be calculated as:

COP = Cooling power / Input power = 50W / 60W = 0.83

Therefore, the COP of the Peltier module refrigeration with a temperature difference of 10°C, 12V and 5A is approximately 0.83.

XII. ADVATNAGES:

- Less weight per unit of refrigeration;
- Lack of moving parts;
- Less frequent maintenance required.
- Operation in any location. ability to use a single module to both heat and cool
- Accurate temperature regulation
- Quiet electrical operation
- No leakage issues
- Spot cooling
- Long life, high reliability

XIII. DISADVANTAGES

- Limited to low heat flux applications;
- less effective in terms of COP

XIV. APPLICATIONS

1. A thermoelectric power plant
2. Communication technology
3.Food production;
4. Medical devices;
5. A cooler for water

XV. CONCLUSION:

A Peltier cooling system is used in the construction of thermoelectric refrigerators. The refrigerator's maximum lowest temperature is constrained by the exhaust fans' irreversibility. Direct contact refrigeration is the sole situation in which thermoelectric cooling is advantageous. It is also established that with the right designs, thermoelectric refrigeration systems can be employed for air conditioning. When employed in moving vehicles, higher cooling capacity. By calculation the COP of the Peltier module refrigeration with a temperature difference of 10°C, 12V and 5A is approximately 0.83. The COP can increase by adding more number of Peltier module.

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