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An Improved Thermo Electric-Based Refrigeration System

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ABSTRACT

This technical report presents the fabrication and performance evaluation of a thermoelectric refrigerator. The project aimed to design an energy-efficient and compact refrigerator utilizing the thermoelectric effect for cooling. The fabrication process involved selecting suitable thermoelectric materials, and implementing efficient heat transfer mechanisms. The refrigerator's performance was evaluated through experiments measuring cooling capacity, coefficient of performance (COP), and temperature uniformity. The fabrication of a thermoelectric refrigerator with a temperature controller represents a significant step toward enhancing the efficiency and lifespan of thermoelectric cooling systems. The successful integration of the temperature controller provides valuable insights into improving the performance and reliability of future thermoelectric refrigeration technologies. The results demonstrated effective cooling and comparable COP to conventional systems. The refrigerator exhibited low power consumption and environmental friendliness due to the absence of harmful refrigerants. This report contributes to sustainable cooling research and showcases the potential of thermoelectric refrigeration technology.This project significantly contributes to the field of thermoelectric refrigeration by integrating a temperature controller into the systemFurther research and development efforts can focus on refining the temperature control algorithm, exploring advanced materials for increased efficiency, and exploring additional applications for thermoelectric cooling in various industries.

Keyword; Cefficient of performance, Temperature, Thermoelectric Refrigerator.

I. INTRODUCTION

1.1 Background of Study

Refrigeration means removing the heat from the subject or space to a lower temperature than the surroundings. Thermoelectric cooling is on the way to eliminating heat from a medium or device by allowing a voltage of unchanged polarity to the junction between two dissimilar semiconductors or electrical conductors. Thermoelectric Refrigeration produces a cooling effect by using the thermoelectric effect (Peltier effect) rather than a common conventional method. Conventional cooling systems used in refrigerators work by a compressor or by working fluid to transfer heat. But here we are avoiding all these methods to absorb Thermal energy. Semiconductors i.e., thermoelectric cooler (also called Peltier cooler) offer several proffer advantages over conventional systems. These are completely solid-state devices, eliminating moving parts, which makes them uneven, quiet, and reliable. There is no way for ozone depletion of CFCs chlorofluorocarbons, offering a more ecologically responsible alternative to conventional refrigeration. They will be ultimate compact than the compressor-based systems. Explicit temperatures (< ±0.1°C) are achieved by Peltier coolers. However, its efficiency is lower than the conventional regular refrigerators. Thus, these are used in suitable applications where their unique advantages override their low efficiency. But still, some large-scale applications are considered (on submarines and aircraft), Peltier coolers are generally utilized where a small size is needed and the cooling exact not too great, such as for cooling electronic devices. Thermoelectric refrigeration is also used in aerospace to control extreme thermal energy that generates in components on the sunlit side and the heated components on the other side. In other scientific applications like digital photo cameras and charge-coupled devices, TER is also used to lower thermal noise, to optimize sensitivity along with image contrast. In compression refrigerators, the coefficient of performance (COP) degrades with the decrease in capacity. Therefore, it is required to design a low-capacity refrigerator, TER is preferable. even it has better control of the open space temperature which is the major advantage of the TER. Hence, TER is the better preference for food preservation & storing insulin. The fabrication of a thermoelectric refrigerator involves several steps, including selecting suitable thermoelectric materials, the device's design, and the components' assembly. The device's performance depends on several factors, including the thermoelectric properties of the materials used, the device's geometry and design, and the system's heat transfer characteristics. To improve the efficiency of thermoelectric refrigerators, researchers are working on developing new materials with higher thermoelectric performance, optimizing device design, and exploring new cooling strategies. One approach is to use multi-stage cooling, where several thermoelectric modules are used in series to achieve a larger temperature difference. Another approach is to use thermal management techniques, such as using heat sinks or other cooling mechanisms to remove heat from the hot side of the device.

1.2 Problem Statement

The refrigeration system is an essential component of modern living, serving a range of purposes such as food preservation, medical storage, and industrial cooling. However, this critical technology faces significant challenges, primarily related to its traditional refrigeration methods. One of the most pressing issues with traditional refrigeration systems is the significant amount of power consumed. The typical refrigerator is a power-hungry device, and this high-power consumption poses a significant challenge for communities that rely on off-grid energy systems. Without reliable access to the power grid, these communities are unable to use traditional refrigeration systems, and this can have dire consequences, particularly for food security and public health. Another problem with traditional refrigeration methods is the use of harmful gases as refrigerants. These chemicals pose a severe threat to the environment, contributing significantly to global warming and ozone depletion. As a result, traditional refrigeration systems are not sustainable, and their continued use poses a significant risk to the planet and all its inhabitants. In addition to the environmental impact, the use of harmful chemicals or gases in traditional refrigeration systems also presents a health hazard to humans. Exposure to these substances can cause respiratory problems, skin irritation, and other adverse health effects, particularly in individuals with preexisting medical conditions. Thus, the development of a sustainable and energy-efficient thermoelectric refrigeration system is critical to address the pressing challenges faced by modern society. By tackling the power consumption and hazardous refrigerants, the creation of alternative refrigeration technologies will provide a significant contribution to a more sustainable and healthier world.

1.3 Aim and Objectives

The aim is to design a thermoelectric refrigeration system and the objectives of the study are to Design a thermoelectric refrigerator, to estimate the amount of heat to be extracted from the system. And Study of thermoelectric machine based on performance and application.

1.4 Significance of the Project

The significance of this study lies in the potential applications of a thermoelectric refrigerator, which is an innovative application of thermoelectric technology in the field of refrigeration. This type of refrigerator has the advantage of being compact, lightweight, and quiet, making it ideal for use in various settings, such as for medical purposes, transportation, or in off-grid locations where traditional refrigeration is not feasible. In thermoelectric refrigeration, a temperature difference is created between two materials by passing an electrical current through them. This temperature difference is then used to drive a refrigeration cycle. Unlike conventional refrigeration systems, thermoelectric refrigeration does not require any moving parts or refrigerants, which could potentially reduce the cost and maintenance requirements of the system. Moreover, thermoelectric refrigeration systems have been suggested to be energy-efficient, as they can directly convert electrical energy into cooling power. This could lead to significant energy savings and a reduction in carbon footprints, making it an Eco-friendly alternative to conventional refrigeration systems. This study may provide new insights into the design, fabrication, and performance of thermoelectric refrigeration systems, addressing a potential research gap in this field. By improving the efficiency, reliability, and durability of thermoelectric refrigeration systems, this study could lead to the development of practical and sustainable refrigeration solutions. Additionally, the study could contribute to the body of knowledge in the areas of thermoelectricity, materials science, and cooling technology, which are essential to the further development and optimization of thermoelectric refrigeration systems.

II. LITERATURE REVIEW

2.1 Overview

Recent research in the field of thermoelectric refrigeration using Peltier modules has focused on developing new materials with higher thermoelectric performance, configurations, and control systems. Other research has explored new designs for Peltier modules, such as asymmetric designs and thin-film Peltier modules. Renato, R. (2016) presented an experimental study of air-conditioning technology and noval potential green refrigeration. Use for analysing the cause and effect of an existing air-condition system. Thermoelectric cooling provides a promising alternative R&AC technology due to their distinct advantages. The available literature shows that thermoelectric cooling systems are generally only around 5– 15% as efficient compared to 40–60% achieved by the conventional compression cooling system [1].Reed, G. H. (1974), researched into a thermoelectric module, designed to analysis the heating and cooling system by using solar energy and which is based on peltier effect. This system is different from other refrigeration system where heating and cooling is done with the help of mechanical devices and by using refrigerants. Bharat M. Jibhakate et al (2016) studied about Thermoelectric Refrigeration model, designed and fabricated in place of compressor and it is based on principle of Peltier effect to maintain effectiveness of both heating and cooling side also the simulation is done to on thermoelectric refrigeration to maintain it at 40°C. Bansal PK, M. A. (2000)., designed and fabricated a thermoelectric refrigerator using one Peltier modules and a thermometer. D. Rajani et al. (2018), fabricated a prototype of solar operated thermo electric cooling system based on peltier effect and its working on solar photo voltage cell generated DC voltage. D. Vashaee, A. A. (2004)., designed the Thermoelectric Refrigeration in place of prime movers and compressor system. Brighthub, E. (2016), carried out a theoretical and experimental analysis of a thermoelectric beverage chiller. Comparison were also made between the thermoelectric beverage chiller's cooling time with cooling times obtained from the freezer space and cold space of a household refrigerator.

This project presents the addition of a temperature controller to thermoelectric refrigerator. While temperature controllers are commonly used in many refrigeration systems, there may be specific challenges or considerations when adding one to a thermoelectric refrigerator.

III. METHODOLOGY

3.1 Materials

In the design of this thermoelectric refrigerator, careful consideration was given to a number of factors such as the thermoelectric nature of the material, cost of the required materials, heat load, insulating properties of the material, and environmental factors.

The materials and components used for the fabrication of the thermoelectric refrigerator are:

3.1.1 Thermoelectric Module

A thermoelectric module, also known as a Peltier module, is a solid-state device that enables the conversion of heat energy into electrical energy or vice versa using the principles of thermoelectric effect.

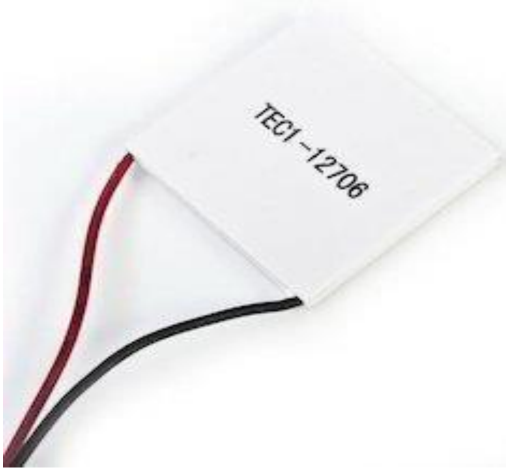
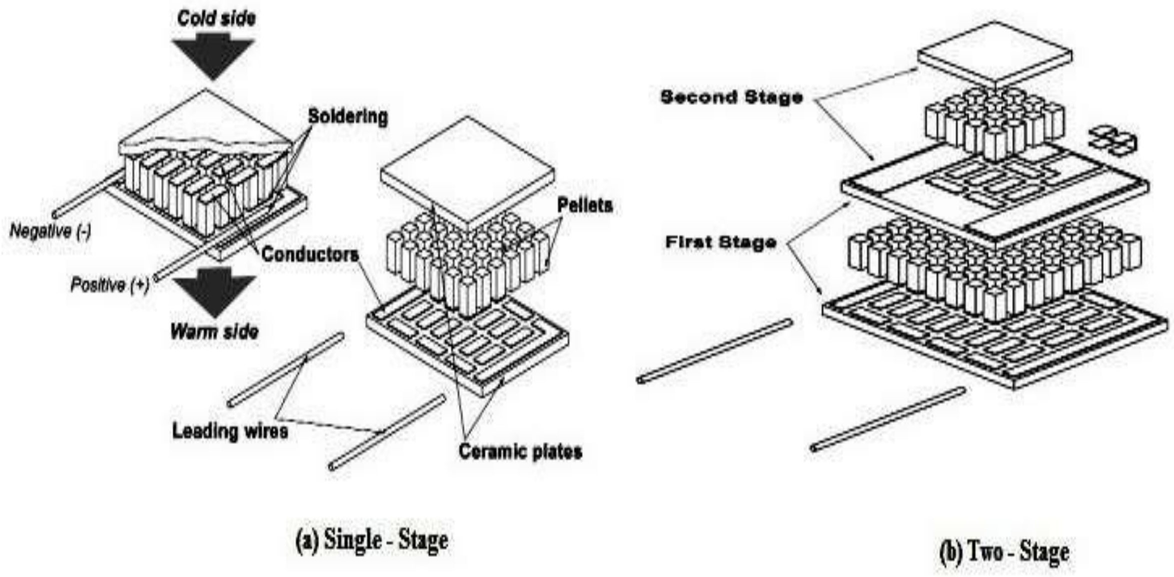


Figure 3.1: Schematic Diagram of a Peltier Module

By applying a low voltage DC power to a TE module, heat will be moved through the module from one side to the other. One module face, will be cooled while the opposite face is simultaneously heated. It is important to note that this phenomenon may be reversed whereby a change in the polarity of the applied DC voltage will cause heat to be moved in the opposite direction. A thermoelectric module may be used for both heating and cooling.



(a) Single - Stage (b) Two - Stage

Figure 3.3: Module Construction

3.1.1.1 Material Selection Criteria

Figure of Merit: The figure-of-merit Z or ZT is the key parameter that determines the efficiency of thermoelectric devices. There are more performance parameters that are usually not presented in standard specifications of commercial TE coolers, but that play a very important role in module characterization. These parameters are the properties of the material (thermal conductance (k), electrical resistance (R), and the Seebeck coefficient) combined as follows:

$$Z = \frac{\alpha^2}{kR}$$

The figure-of-merit Z has a unit of inverse Kelvin and therefore, often appears as a dimensionless product with an absolute temperature. To maximize the thermoelectric figure of merit (zT) of a material, a large thermopower (absolute value of the Seebeck coefficient), high electrical conductivity, and low thermal conductivity are required.

The best ZT materials are found in heavily-doped semiconductors. Seebeck coefficient and high thermal conductivity. It is estimated that materials with ZT>3 are required to replace traditional coolers in most applications. The figure of merit can be improved by independently adjusting these properties.

Thermal Conductivity

$\kappa = \kappa$ electron + κ phonon

According to theWiedemann–Franz law, the higher the electrical conductivity, the higher κ electron becomes. Therefore, it is necessary to minimize κ phonon. In semiconductors, κ electron < κ phonon, so it is easier to decouple κ and σ in a semiconductor through engineering κ phonon.

Electrical Conductivity: Metals are typically good electrical conductors, but the higher the temperature, the lower the conductivity, given by the equation for electrical conductivity:

$\sigma_{metal} = ne2\tau/m$

- n is carrier density
- e is electron charge
- τ is electron lifetime
- m is mass

As temperature increases, τ decreases, thereby decreasing σ_{metal}. By contrast, electrical conductivity in semiconductors correlates positively with temperature. $\sigma_{semiconductor} = ne\mu$

- n is carrier density
- e is the electron charge
- μ is carrier mobility

Carrier mobility decreases with increasing temperature, but carrier density increases faster with increasing temperature, resulting in increasing σ semiconductor.

3.1.1.2 Specification of Thermoelectric Module

Table 3.1: Specifications of Thermoelectric Module

Model Number	TEC1-12705
Voltage	12V
U_{max}(V)	15.4V
I_{max} (A)	6A
Q_{max} (W)	92W
Internal Resistance	1.98 Ohm +/- 10%
Dimensions	40mm × 40mm × 3.6mm
Power Cord	350mm
HS Code	854150
Certification	RoHS
Type	Cooling Cells
Usage	Refrigerator/Warmer

3.1.2 Heat Sink

In electronic systems, a heat sink is a passive component that cools a device by dissipating heat into the surrounding air. Heat sinks are used to cool electronic components such as high-power semiconductor devices, and optoelectronic devices such as higher-power lasers and light-emitting diodes (LEDs). Heat sinks areheat exchangersuch as those used in refrigeration and air conditioning systems.

Figure 3.4: 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.

3.1.2.1 Basic Heat Sink Heat Transfer Principle

A heat sink is an object that transfers thermal energy from a higher temperature to a lower temperature fluid medium.Consider a heat sink in a duct, where air flows through the duct, as shown in figure above. It is assumed that the heat sink base is higher in temperature than the air. Applying the conservation of energy, for steady-state conditions, andNewton's law of coolingto the temperature nodes gives the following set of equations.

$$\dot{Q} = \dot{m}c_{p,in}\left(T_{air,out} - T_{air,in}\right) \quad (1)$$

$$\dot{Q} = \frac{T_{hs} - T_{air,av}}{R_{hs}} \quad (2)$$

Where;
$$T_{air,av} = \frac{T_{air,out} + T_{air,in}}{2} \quad (3)$$

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

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 in 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

3.1.3 Cooling Fan

The axial-flow fans have blades that force air to moveparallelto the shaft about which the blades rotate. Axial fans blow air along the axis of the fan, linearly, hence their name.

Figure 3.6: Axial flow cooling fans

Fans applications ranges from small cooling fans for electronics to the giant fans used inwind tunnels. Axial flow fans are applied for air conditioning and industrial process applications. Standard axial flow fans have diameters from 300-900 mm and work under pressures up to 800 Pa.

3.1.4 Thermal Grease

Thermal grease is primarily used in the electronics and computer industries to assist a heat sinkto draw heat away from a semiconductorcomponent 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).

3.1.5 Switched Mode Power Supply (SMPS)

SMPS is a type of power supply that converts AC (alternating current) to DC (direct current) by using a switching regulator. SMPS is commonly used in electronic devices such as computers, routers, LED lights, and other consumer electronics that require a low (12V) DC voltage to operate. It uses a switching regulator to convert the input voltage to a fixed 12V DC voltage output. The switching regulator operates at high frequency, typically in the range of 50 kHz to 100 kHz, to provide a more efficient conversion than linear power supplies.

An SMPS works by first rectifying the incoming AC power to DC power. The DC power is then filtered and stored in a capacitor bank. The switching regulator then takes the DC voltage and switches it on and off rapidly at a high frequency, typically between 50 kHz and several MHz. The output is then smoothed and filtered to produce a steady DC voltage that is used to power the device..

Figure 3.7: 12V SMPS

3.1.6 Digital Temperature Controller

The digital temperature controller works by measuring the temperature of the system using a temperature sensor, such as a thermocouple or RTD (resistance temperature detector), and comparing it to the desired temperature set by the user. If the measured temperature deviates from the desired temperature, the controller will activate a heating or cooling device, such as a heater or chiller, to bring the system back to the desired temperature.

Figure 3.8: XH-W3001 temperature controller

3.2 Material Performance Requirements

The likely modes of failure and the corresponding material properties that are needed to resist failure on the components are Corrosion,Deformation,Thermal conductivity, Reliability and Efficiency of components in service.

3.2.1 Force Analysis

At this stage of the project, the forces acting on each member of the machine and the energy transmitted by each member are analyzed which is the load and frame

3.3 Design Analysis

In designing a thermoelectric cooling system, one of the most critical processes is to reach an understanding of the thermal load. With this vital information, we can able to choose the best TE device or heat exchangers for the job..

3.3.1 Heat Load Calculation

The two elements of thermal load in thermoelectric refrigeration systems include active and passive loads. Active load is considered whenever part of the load actually produces heat.

Passive heat load: First we have to identify the greatest temperature difference between the thermal load and the ambient environment that can occur. The worst-case difference between the ambient and load temperatures will be the temperature difference, ‘ΔT’ in the equations which follow. Including both the conductive and convective heat transfer components of the load, we can use this equation:

$$Q = \frac{\Delta T * A}{\frac{1}{h}+\frac{L}{k}}$$

Temperature to be maintained inside the cabin = 20 ^{0}C

Outside temperature or ambient temperature = 32 ^{0}C

Temperature difference between the cabin walls = 32 – 20 = 12 ^{0}C

K_{MS} = 52 W/mK

K_{EPS} = 0.033 W/mK h $_{AIR}$ = 10 W/m^{2}K

Area, $A_1 = A_2 = A_3 = 0.50 \text{ x } 0.50 = 0.25 \text{ m}^2$

$$Q = \frac{\Delta T \cdot A}{\frac{2*1}{h_{air}}+\frac{l_1}{k_{EPs}}+\frac{l_2}{k_{MS}}}$$

$$Q = \frac{0 \cdot 25 * 12}{\frac{2*1}{10}+\frac{0.05}{0.033}+\frac{0.002}{52}} = 1.75\text{w}$$

i.e., $Q_1 = Q_2 = Q_3$ = 2.92W Passive load through the walls,

$Q_P = (Q_1 + Q_2 + Q_3) \text{ x } 2 = (1.75+1.75+1.75) \text{ x } 2$
= 10.5 W ≈ 11W

Infiltration air load due to opening and closing, Q_C ≈ 10 W

$Q_{TP} = Q_P + Q_C$ = 11 + 10 = 21 W

For safety, Q_{TP} ≈ 25 W

3.3.2 Tec Selection

It is required to choose a TEC module that not only has sufficient cooling capacity to maintain the proper temperature, but also meet the dimensional requirements imposed by the housing

3.3.3 Heat Sink Selection

The values obtained in the preceding analysis are used to assess overall system feasibility. We want to qualify our assumption of 15°C temperature rise across heat sink. Most of the thermoelectric cooling applications use forced convection heat sinks with thermal resistance values (R_{ht}) ranging from 0.10 ^{0}C/W to 0.5^{0}C/W.

Using the known values for T_A, V, I, and Q, R_{ht} is solved to determine if it is reasonable

$R_{HT} = (T_H - T_A) / (V \text{ x } I + Q)$

R_{HT} = (47 - 32)/ (12 x 5 + 20) = 0.176 ^{0}C/W

Our proposed system using a TEC1-12706 module and a forced heat sink meets the criteria for this application.

Heat load required to be dissipated from hot side: The Peltier module is running at 12V and 5 amps of current at nominal operation

$Q_H = P_{TEC} + Q_T = 4 \text{ x } V \text{ x } I + Q_T$
= 4 x 12 x 5 + 30 = 270 W

So, Aluminum heat sink must be able to dissipate about 270W of heat load from the Peltier module.

3.5.4 Determination of Insulation Thickness

To achieve efficient cooling, it is essential to maintain a significant temperature difference between the cold and hot sides of the refrigerator.

3.5.5 Selection of the SMPS

To determine the expected current and amp rating of the SMPS needed for thermoelectric refrigerator, we calculate the total power consumption of the system.

3.5.6 Selection of Temperature Controller

To control the temperature of your thermoelectric refrigerator, We used a PID temperature controller. PID stands for Proportional-Integral-Derivative, which is a type of feedback control algorithm used in industrial control systems to regulate temperature, pressure, flow, and other process variables. In a PID temperature controller, the control output is calculated based on the proportional, integral, and derivative terms, which are determined by measuring the error between the desired set-point temperature and the actual temperature, as well as the rate of change of the error over time. To select a suitable PID controller, you will need to consider the specifications of your system. The controller should be able to handle the voltage and current ratings of the peltier modules, and the temperature range of your refrigerator. Assuming that each TEC1-12706 peltier module has a maximum current rating of 6A and a maximum voltage of 15.4V, the maximum power consumption of each module is:

Max power consumption = 6A x 15.4V = 92.4W

Therefore, the maximum power consumption for all four modules is:

Total power consumption = 4 x 92.4W = 369.6W

We selected a PID controller that can handle the voltage and current requirements of the peltier modules, as well as the maximum power consumption of the system. It is recommended to choose a controller with a power output rating that is higher than the maximum power consumption of the system, to provide a margin of safety.

Since we are using a 12V DC power supply, the maximum current draw of the system is:

Max current draw = Total power consumption / 12V

Max current draw = 369.6W / 12V

Max current draw = 30.8A

So, we selected a PID controller that can handle a current rating of at least 30.8A. We also chose a controller with a temperature range that matches the requirements of our refrigerator.

3.6. Electrical Design of the Thermoelectric Refrigerator

The power cable was connected to a switch, which was then wired to an SMPS to convert the AC power to DC 12V. The four fans responsible for cooling the hot sink and circulating cool air from the inside of the refrigerator were then connected to the SMPS. Furthermore, the SMPS was wired to an XH-W3001 temperature controller. The four Peltier modules were subsequently wired to the temperature controller, which was programmed to turn them off when the desired temperature was achieved. It is worth noting that appropriate wire gauge was used to ensure that the current draw of the fans, Peltier modules, and temperature controller was adequately handled. Finally, a fuse or circuit breaker was included in the wiring setup to protect against overcurrent and prevent electrical fires. Prior to use, the wiring setup was thoroughly tested to ensure safe and proper functioning of the temperature controller, fans, and Peltier modules.

IV. RESULTS AND DISCUSSION

4.1 Testing Procedure

The system was tested to determine the performance of the various components. In order to make sure that the system fulfills the design requirement of keeping a fixed temperature, test was piloted with initial temperature of load at required temperature. A stop watch was used to take measurement of the time the system cooled from ambient temperature to the desired temperature and the readings recorded. The readings were taken in intervals of 5 minutes. The results from the observation was used to plot a graph of temperature against time.

4.1.1 Time Taken to Cool Refrigerator to Require Temperature

After the system was constructed, a test to determine the time it will take to attain the desired temperature was conducted. When the designed system was tested, it was found that the inner temperature of the refrigeration area was reduced from 32℃ to 23.5 ℃ in 98 minutes.

Table 4.1 : Table of Temperature and Time for Cooling

Time (mins)	Temperature(°c)
0	32.1
10	31.3
20	29.7
30	28.6
40	27.5
50	26.1
60	25.4
70	24.8
80	24.0
90	23.6
100	23.5

4.1.2 Coefficient of Performance

The explanation below shows how the coefficient of performance of the refrigerator (COP_R) was calculated. It was assumed that the system used to cool a total of 2.0 L water from 32℃ to 26℃ in 108 minutes. Properties of water for these calculations are. (density =1 kg/L and C= 4.18 kJ/kg)

The heat removed by the thermoelectric system can be calculated using the following formula:

$Q = m \times C \times \Delta T$

where Q is the amount of heat removed, m is the mass of water, C is the specific heat capacity of water, and ΔT is the temperature difference.

Given that the system cools a total of 2.0 L of water from 32 to 26 degrees Celsius, we can calculate the mass of water as follows:

$m = \rho \times V$

where ρ is the density of water and V is the volume of water.

Substituting the values, we get:

$m = 1\ \text{kg/L} \times 2.0\ \text{L} = 2.0\ \text{kg}$

The temperature difference can be calculated as:

ΔT = 32 - 26 = 6 degrees Celsius

Substituting the values into the formula, we get:

$Q = 2.0\ \text{kg} \times 4.18\ \text{kJ/kg°C} \times 6\text{°C} = 50.16\ \text{kJ}$

The cooling capacity of the thermoelectric system can be calculated as follows:

Cooling capacity = Q / t

where t is the time taken to cool the water.

Given that the system takes 108 minutes to cool the water, we can calculate the cooling capacity as follows:

Cooling capacity = 50.16 kJ / 108 min = 0.464 kJ/min

The COP of a thermoelectric system can be calculated using the following formula:

$COP = Q_c / W$

where Qc is the amount of heat removed from the cold reservoir and W is the electrical power consumed by the system.

From the previous calculation, we know that the amount of heat removed by the thermoelectric system is 50.16 kJ. To calculate the electrical power consumed by the system, we need to know the voltage and current supplied to the Peltier modules.

Assuming a typical voltage drop of 0.6 V per module and a maximum current rating of 6 A per module for the TEC1-12706 Peltier module, the total electrical power consumed by the four modules can be estimated as follows:

$W = V \times I \times N$

where V is the voltage drop per module, I is the maximum current rating per module, and N is the number of modules.

Substituting the values, we get:

$W = 0.6\ \text{V} \times 6\ \text{A} \times 4 = 14.4\ \text{W}$

Therefore, the COP of the thermoelectric system can be calculated as follows:

$COP = Q_c / W = 50.16\ \text{kJ} / 14.4\ \text{W} = 3.48$

This indicates that the thermoelectric system has a COP of 3.48, meaning that for every 1 watt of electrical power consumed, the system can remove 3.48 watts of heat from the cold reservoir.

4.2 Discussion of Result

Based on the results obtained, it can be concluded that the introduction of a temperature controller has significantly improved the efficiency of the thermoelectric refrigerator. The COP value of 3.48 indicates that the system is able to remove a considerable amount of heat from the cold reservoir for every unit of electrical power consumed by the Peltier modules.The use of a temperature controller has also helped to regulate the temperature inside the refrigerator, allowing it to maintain a temperature range of 25-20°C, which is within the desired range. The controller ensures that the Peltier modules are turned off when the desired temperature is reached, which helps to conserve energy and prolong the lifespan of the Peltier modules.However, it is worth noting that the time taken for the temperature inside the refrigerator to drop from 32°C to 23.5°C is 98 minutes, which may be considered relatively slow. This could be attributed to factors such as the thermal insulation of the refrigerator and the thermal conductivity of the Peltier modules. Further optimization of the thermal management of the system, such as improving the insulation and selecting Peltier modules with higher ZT values, could help to improve the cooling performance of the thermoelectric refrigerator.Overall, the project has demonstrated the potential of thermoelectric refrigeration as a viable alternative to traditional refrigeration technologies, with the added advantage of being more compact, quieter, and environmentally friendly. Further research should lead to adoption of thermoelectric refrigeration in various applications.

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the successful fabrication of a thermoelectric refrigerator with an integrated temperature controller has demonstrated its potential as an efficient and reliable cooling system. The temperature controller effectively regulated the internal temperature of the refrigerator, ensuring optimal cooling conditions while extending the lifespan of the Peltier modules.By continuously monitoring the temperature inside the refrigerator using the temperature sensor, the temperature controller accurately determined when to activate or deactivate the Peltier modules. This precise control allowed the refrigerator to maintain a stable temperature, preventing temperature fluctuations that could affect the stored contents. Moreover, by turning off the Peltier modules once the desired temperature was reached, the temperature controller reduced the overall strain on the modules, contributing to their longevity and enhancing the overall lifespan of the refrigerator.The integration of the temperature controller addressed the knowledge gap of effectively managing the operation of the Peltier modules, which is crucial for the long-term performance and durability of thermoelectric refrigerators. By automating the cooling process and minimizing human intervention, the temperature controller ensures consistent and reliable temperature control, making the refrigerator suitable for a wide range of applications.

Furthermore, this project highlights the potential of thermoelectric cooling systems as a sustainable alternative to conventional refrigeration technologies. The absence of harmful refrigerants and the compact and lightweight nature of thermoelectric refrigerators make them particularly suitable for portable and small-scale cooling applications, such as in medical, pharmaceutical, and camping equipment.

In summary, the fabrication of a thermoelectric refrigerator with a temperature controller represents a significant step toward enhancing the efficiency and lifespan of thermoelectric cooling systems. The successful integration of the temperature controller provides valuable insights into improving the performance and reliability of future thermoelectric refrigeration technologies. Further research and development efforts can focus on refining the temperature control algorithm, exploring advanced materials for increased efficiency, and exploring additional applications for thermoelectric cooling in various industries.

5.2 Recommendation

To further improve the thermoelectric refrigerator with a temperature controller and expand its applications, the following recommendations can be considered:

- Optimize the temperature control algorithm to minimize temperature fluctuations and improve energy efficiency.
- Enhance the efficiency of the Peltier modules by exploring advanced materials and optimizing their design.
- Implement energy management strategies such as energy-saving modes and the integration of renewable energy sources to improve energy efficiency.
- Explore advanced thermal management techniques, such as phase change materials, to enhance heat dissipation and improve cooling efficiency.
- Investigate advanced temperature sensing methods, including multiple sensors and non-contact techniques, for more accurate and reliable temperature measurements.
- Explore the integration of IoT technologies for remote monitoring, control, and data analysis of the refrigerator.By addressing these recommendations, the performance, efficiency, and versatility of the thermoelectric refrigerator with a temperature controller can be enhanced, contributing to its broader adoption and promoting sustainable cooling solutions.

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