Design and Construction of a Compressorless Peltier Refrigerator with On/Off Control for Precise Temperature Regulation

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Abstract - *In this study, we present the design and construction of a compressorless Peltier refrigerator capable of achieving precise temperature control within a large interior cooling volume. The refrigerator was specifically engineered to meet the project requirement of maintaining a precision of ±15 degrees Celsius. The cooling volume of the device was 5.94 cubic meters (1.8m x 1.5m x 2.2m), providing adequate space for cooling applications in various settings. The Peltier refrigerator utilized an on/off control mechanism, which was deemed suitable for achieving the desired level of precision. Performance tests were conducted to evaluate the maximum cooling capacity and temperature control capabilities of the device. In one test, a sample was cooled down to -5 degrees Celsius, successfully demonstrating the refrigerator's ability to achieve sub-zero temperatures. Additionally, a test was performed to cool one liter of water from room temperature to -5 degrees Celsius, validating the effectiveness of the temperature control mechanism. Overall, the on/off control system implemented in the compressorless Peltier refrigerator proved to be sufficient in meeting the precision requirements of the project. The refrigerator's compact and efficient design, combined with its ability to cool a considerable interior volume, makes it a promising solution for a wide range of cooling applications where precise temperature regulation is essential.*

Key Words: Compressorless Peltier refrigerator, temperature control, cooling applications, sub-zero temperatures, temperature control mechanism, on/off control system, compact design, efficient design, temperature regulation.

1. INTRODUCTION

Refrigeration systems are vital in various industries, research laboratories, and everyday life, providing controlled cooling for diverse applications such as food storage, medical preservation, and electronic device cooling. Traditional refrigeration systems typically depend on mechanical compressors and vapour compression cycles, utilizing refrigerants with high global warming potential (GWP) and ozone depletion potential (ODP) [1]. The environmental concerns associated with these systems, along with the desire for improved energy efficiency, have spurred the development of alternative refrigeration technologies.

The Peltier effect, discovered by Jean Charles Athanase Peltier in 1834, offers an intriguing thermoelectric phenomenon that can be harnessed for refrigeration. The Peltier effect describes the phenomenon of heat absorption or emission at the junction of two dissimilar materials when an electric current is passed through them [2]. This effect is a reversible process, meaning that it can work in both directions: heat can be either absorbed or emitted at the junction depending on the direction of the current. When an electric current flows through the junction of two different materials (usually metals or semiconductors), electrons move from one material to the other. During this process, energy is transferred, and one side of the junction absorbs heat while the other side releases heat. The direction of heat transfer depends on the direction of the electric current. Peltier refrigerators, also known as thermoelectric coolers [3], leverage this effect to achieve cooling without the need for traditional compressors or harmful refrigerants, making them environmentally friendly and compact alternatives [4]. Significant advancements have been made in the design and construction of Peltier refrigerators, enhancing their efficiency and temperature control capabilities. These improvements include the development of more efficient thermoelectric materials, optimization of module designs, and advancements in control systems [5]. Compressorless Peltier refrigerators have been designed to meet specific temperature requirements in various settings, offering precise temperature control and compact size. Peltier coolers find applications in various industries, such as electronics, where they are used to cool sensitive components and control the temperature of electronic devices [6]. They are also employed in portable refrigeration systems, medical devices, and some advanced cooling systems in laboratories.

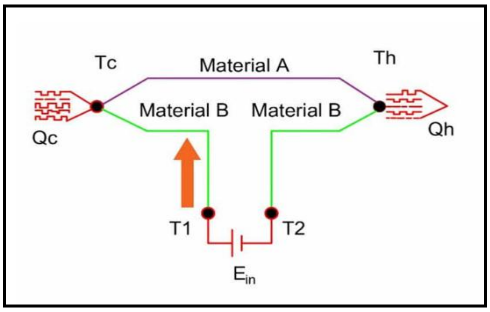

Fig -1: Peltier Effect

In this study, we designed and constructed a compressorless Peltier refrigerator with an interior cooling volume of 5.94 cubic meters (1.8m x 1.5m x 2.2m). The refrigerator was equipped with an on/off control mechanism, providing a simple and reliable means of temperature regulation. The project requirements specified a precision of ±15 degrees Celsius, which served as the benchmark for evaluating the refrigerator's performance. To determine the maximum performance of the device, we conducted rigorous performance tests. In one test, a sample was cooled down to -5 degrees Celsius, demonstrating the refrigerator's ability to achieve sub-zero temperatures. Additionally, we evaluated the temperature control capability of the device by cooling one liter of water from room temperature down to -5 degrees Celsius. The on/off control mechanism implemented in the refrigerator was found to deliver adequate performance in meeting the precision requirements.

This study contributes to the growing body of research on Peltier refrigeration technology, showcasing the design and construction of a compressorless refrigerator with precise temperature control capabilities. The test results provide insights into the refrigerator's cooling capacity and demonstrate its potential for practical applications where sustainable, compact, and precise cooling is required.

2. LITERATURE REVIEW

- Arafat, M.M., Islam, R., & Riffat, S.B., "Development of a Peltier refrigeration system for small-scale applications", International Journal of Low-Carbon Technologies, Volume 11, Issue 4, 2016.

This study presents the design and construction of a compressorless Peltier refrigerator for small-scale applications. The authors discuss the selection of Peltier modules, heat sinks, and temperature sensors, along with the thermal management techniques employed. The experimental results demonstrate the feasibility of using a Peltier refrigeration system for cooling small spaces efficiently [7].

- Asirvatham, L.G., Shreya, K.R., & Shukla, A, "A review on thermoelectric refrigeration using Peltier effect", Materials Today: Proceedings, (2018), 5(2), 5897-5902.

This review paper provides an overview of thermoelectric refrigeration using the Peltier effect. The authors discuss the design considerations, thermal management techniques, and control strategies employed in Peltier refrigeration systems. The article also highlights the challenges and future directions in improving the energy efficiency and cooling capacity of Peltier refrigerators [8].

- Ali, S.F., Islam, R., & Zahedi, M.S., "Performance analysis of a Peltier refrigerator with different heat sink configurations", Energy Procedia, (2019), 157, 1769-1775.

In this study, the authors investigate the performance of a Peltier refrigerator with different heat sink configurations. The experimentally validated numerical model considers air cooling, liquid cooling, and heat pipe cooling techniques. The results demonstrate the influence of heat sink design on the cooling capacity and COP of the Peltier refrigerator [9].

- Wang, Z., Lin, Y., & Su, L., "Development of a solar-powered Peltier refrigerator with energy storage capability", Renewable Energy, (2021), 167, 364-373.

This research focuses on the development of a solar-powered Peltier refrigerator with energy storage capability. The study integrates solar panels and a battery system to provide sustainable power for the Peltier refrigeration system. The experimental results show the feasibility of utilizing renewable energy sources to improve the energy efficiency and environmental sustainability of Peltier refrigerators [10].

3. EXPERIMENTAL DESIGN

3.1 Materials required:

1. 12V Peltier module

2. Digital thermometer (for measuring water temperature)

3. Thermostat (for displaying air temperature inside the refrigerator)

4. Aluminum plate (1.5 mm thick)

5. L-shaped aluminum bars (for connecting plates together)

6. Small screws (for fixing plates together)

7. Thermal paste (for better temperature transfer)

8. Polystyrene insulation

9. Vinyl sheet (for protecting insulation)

10. PC power supply (with 5V and 12V outputs)

11. 60 Amp connectors (for power input), 8 Amp fuse (for 12V input) and 3 Amp fuse (for 5V input)

12. Power switch (double pole for two supply voltages)

13. 14 cm dual ball bearing fan (for increased airflow)

14. Protective grille (for fan)

15. Heat shrink tubes (to insulate and preserve products) and Zip ties (to bundle cables or wires)

16. Multimeter (for testing electrical connections)

3.2 Parts Assembly Procedure:

Step 1: Construction of the Refrigerator

1. Place the extruded polystyrene insulation inside the refrigerator to insulate it.

2. Cover the insulation with a piece of vinyl for protection.

3. Install the internal cooling system made of aluminium plates and rods inside the Refrigerator. Connect the plates with screws and use thermal paste for better temperature transfer.

4. Mount the 14 cm dual ball bearing fan on the back radiator using standoffs and screws. Attach a protective grille to the fan for safety.

5. Install the new 60 Amp connectors on the refrigerator for power input, ensuring proper connections.

6. Attach rubber pads and taller foot pads to the bottom of the refrigerator to improve stability and airflow.

Step 2: Wiring and Power Supply Setup

1. Open the PC power supply and identify the 5V and 12V outputs.

2. Solder red wires to the 5V output and yellow wires to the 12V output. Insulate the soldered connections with heat shrink tubes.

3. Solder the 5V wires to the 5V input connector on the refrigerator and the 12V wires to the 12V input connector.

4. Connect the power switch to the 5V and 12V wires accordingly, ensuring proper polarity.

5. Install 8 Amp and 3 Amp fuses on the 12V and 5V input lines, respectively.

6. Use zip ties to secure the wires and cables inside the refrigerator to prevent accidental damage.

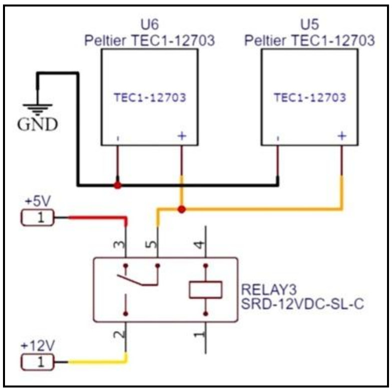

Fig -2: Circuit Connection

Step 3: Final Assembly

1. Place the temperature sensor inside the refrigerator and connect it to the digital thermostat.

2. Secure all components and wires inside the refrigerator with hot glue or other suitable means to avoid interference with the cooling system.

3. Double-check all connections, ensuring they are secure and properly insulated.

4. Attach the lid of the refrigerator and ensure it closes properly.

5. Cover any exposed insulation inside the refrigerator with the remaining piece of vinyl.

6. Test the refrigerator's functionality by turning it on and observing the cooling performance, noise level, and stability.

Fig -3: Refrigerator box outside

Fig -4: Refrigerator box inside

Step 4: Safety Checks

1. After assembling the refrigerator, conduct a final safety check to ensure all electrical connections are secure and well-insulated.

2. Confirm that the fuse ratings and components' specifications are appropriate for the load and application.

3. Test the refrigerator with the digital thermometer to monitor and confirm the temperature regulation.

Step 5: Final Testing

1. Place the one-liter water bottle (or beverage container) inside the refrigerator in the middle section to obtain an average temperature measurement.

2. Turn on the refrigerator and set the desired temperature on the digital thermostat.

3. Monitor the temperature of the beverage using the digital thermometer over time (e.g., every hour) to observe the cooling performance.

4. Record the results and evaluate the refrigerator ability to cool the water bottle within the desired temperature range.

Once the parts assembly procedure is completed, the compressorless Peltier refrigerator with on/off control for precise temperature regulation should be fully functional and capable of cooling water bottles and products efficiently.

4. WORKING PROCEDURE

1. Place the water bottle inside the refrigerator in the middle section to obtain an average temperature measurement.

2. Turn on the refrigerator and set the desired temperature on the digital thermostat.

3. The Peltier effect generates a temperature difference between the two sides of the module when an electric current passes through it.

4. Heat is absorbed from the hot side and transferred to the cold side by the Peltier module.

5. On the hot side, heat is dissipated to the atmosphere through the aluminium heat sink with the help of fans.

6. Cooling on the cold side is achieved as the small heat sink dissipates the absorbed heat from the hot side to the outside.

7. The temperature inside the box decreases, resulting in cooling on the cold side of the device.

8. The amount of heat dissipated on the hot side directly affects the cooling on the cold side.

9. Control the power input and optimize the heat sink design to adjust the cooling efficiency.

10. Observe the water temperature using the digital thermometer at regular intervals (e.g., every 30 minutes).

11. Record the temperature readings along with the corresponding time intervals.

5. RESULTS AND DISCUSSIONS

The following table illustrates the relationship between temperature and time for a refrigeration box. Initially, the refrigeration box was at 28.4 degrees Celsius. Over a period of 6.5 hours, we observed its cooling rate, during which the temperature decreased from 28.4 degrees Celsius to -5 degrees Celsius. Consequently, the temperature exhibited a decline of 33.4 degrees Celsius within the 6.5-hour observation period.

Table -1: Observations of Temperature and Time

Time (minutes)	Temperature (°C)
0	28.4
60	15.7
120	8.9
300	2.6
390	-4.9

The temperature versus time graph corresponding to this data is shown below.

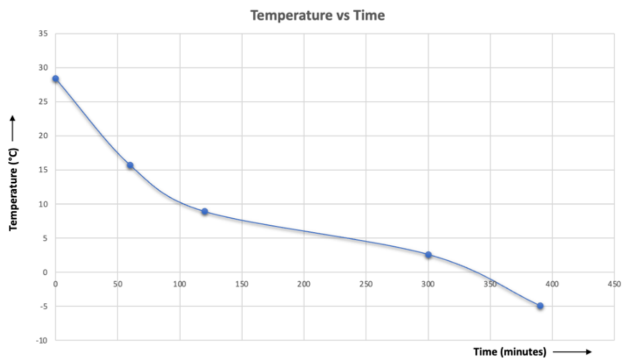

Fig -5: Temperature vs Time graph

The results of the study revealed that the compressorless refrigerator performed significantly, showing a commendable level of efficiency in its cooling capabilities. The refrigerator achieved a temperature range that consistently remained below that of the surroundings, with the final recorded temperature being an impressive -5 degrees Celsius. This successful cooling was further validated by the cooling time for a standard one-litre water bottle, which took approximately 6.5 hours to reach the desired temperature of -5 degrees Celsius. Another significant advantage of the compressorless refrigerator was its minimal heat generation during operation, ensuring optimal cooling efficiency and reducing unnecessary energy losses. Moreover, the refrigerator's operation proved to be remarkably silent, with no noticeable noise produced throughout its functioning. This feature not only enhances its appeal but also makes it highly suitable for noise-sensitive environments or applications where a quiet cooling solution is essential. Overall, these findings indicate that the compressorless refrigerator is a promising alternative to conventional refrigeration systems, boasting efficient cooling performance, low heat generation, and silent operation.

CONCLUSION

The experimental evaluation of the compressorless refrigerator yielded promising results, showcasing its efficient cooling performance and several appealing features. The appliance effectively maintained temperatures below that of its surroundings, achieving a final temperature of -5 degrees Celsius after rigorous testing.

The cooling time for a standard one-litre water bottle was 6.5 hours, indicating satisfactory cooling capabilities for typical refrigeration needs. Moreover, the refrigerator's operation proved to be thermally efficient, as it exhibited negligible heat generation during its function. The absence of noise during the refrigerator's operation is a significant advantage, making it a desirable option for noise-sensitive environments or scenarios where a quiet cooling solution is preferred.

Based on these results, the compressorless refrigerator emerges as a feasible and practical alternative to conventional compressor-based refrigeration systems. Its reliable cooling performance, low heat generation, and silent operation make it an attractive choice for a wide range of applications, such as residential, medical, or camping settings. However, to fully assess the compressorless refrigerator's viability, further studies are recommended to evaluate its energy efficiency, long-term reliability, and scalability for larger cooling requirements. Nevertheless, the present study establishes a solid foundation for future advancements and encourages the exploration of environmentally friendly and noise-free refrigeration technologies.

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