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Experimental Investigation of Peltier Effect in Small Scaled Refrigerator

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Abstract— The cooling effect can be achieved with a number of different systems. Concern over the production, use, and disposal of hydro chlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs) as heat carrier fluids in conventional refrigeration and air conditioning systems has grown in recent years, leading to a great deal of research into the creation of innovative refrigeration and space conditioning technologies. Our project's primary goal is to construct and evaluate the impact of Peltier modules on cooling based on volume variations of small, environmentally friendly refrigerators of various sizes.

Keywords— Refrigeration systems, Environmental degradation, ChloroFluoroCarbons (CFCs), HydroChlorofluorocarbons (HCFCs), Heat carrier fluids, Eco-friendly refrigeration, Peltier modules, Cooling effect analysis, Compact refrigerators.

I. INTRODUCTION

A. Peltier Effect

Thomas Seebeck and Jean-Charles Peltier discovered the Peltier effect, a thermoelectric phenomenon, in 1834. A temperature differential at the junctions is produced when an electric current passes through a circuit composed of two distinct conducting materials. An array of semiconductor pellets made of bismuth telluride makes up a standard thermoelectric module.

Heat is absorbed by one connection (cooling effect) and released by the other (heating effect). Which junction cools and which heats depends on the direction of the current. Applications for thermoelectric cooling, including computer cooling systems, portable refrigerators, and precision temperature control devices, frequently employ this effect.

B. Peltier Module

A Peltier module, also known as a thermoelectric cooler (TEC), is a compact device that utilizes the Peltier effect to transfer heat between its two sides. It consists of multiple pairs of p-type and n-type semiconductor elements connected electrically in series and thermally in parallel, sandwiched between two ceramic plates.

When an electric current passes through the module, one side absorbs heat (cooling effect), while the other side releases it (heating effect). Peltier modules are used in applications requiring precise temperature control, such as cooling electronic components, medical devices, portable refrigerators, and even in certain climate control systems.

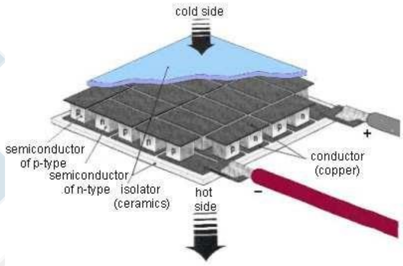

Fig. 1. A Peltier Module

The naming scheme for Peltier modules typically follows a standardized format indicating their key specifications.

a) Series/Type: Indicates the module family or type (e.g., TEC, TES, or custom manufacturer codes).
b) Number of Pairs: Specifies the number of semiconductor element pairs, often correlating to the module's capacity (e.g., 127 = 127 pairs).
c) Dimensions: Provides the module's physical size in millimeters (e.g., 40×40 mm for a square module).
d) Maximum Current: Indicates the maximum operating current in amperes (e.g., 6A).

For example, TEC1-12706 can be interpreted as:
TEC: Thermoelectric cooler.
1: Series.
127: 127 semiconductor pairs.
06: Maximum current of 6A.
Always refer to the datasheet for detailed specifications.

C. Advantages of Peltier Refrigerators

a) Compact and Lightweight: Ideal for portable and space-constrained applications.
b) No Moving Parts: Ensures quiet operation and reduces wear and tear, increasing reliability.
c) Environmentally Friendly: No refrigerants or harmful chemicals are used.

d) Durable and Long-lasting: Solid-state construction enhances longevity.
e) Flexible Orientation: Can operate in any physical orientation without performance issues.
f) Low Maintenance: Minimal upkeep required due to the absence of mechanical components.

II. SET-UP DESCRIPTION

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

A. Project Idea:

The idea behind this project is to find out the effect of variation in volume of cooling space on cooling capability of Peltier module. The formula for heat absorption by Peltier module doesn't account the effect of volume of cooling space. Thus, three models of different sizes (small, medium, large) are made to investigate and analyze the effect of volume on cooling capacity of Peltier module.

B. Dimensions:

The table provides the dimensions of refrigerators for three different models categorized as Small, Medium, and Large, based on their size. Each model's length, width, height and volume are specified.

	Length (cm)	Width (cm)	Height (cm)	Volume (l)
Small	20	20	23	4.8
Medium	23	23	28	8.6
Large	26	26	35	15

C. Materials Used:

The below list outlines the materials employed

a) TEC 12706 Peltier Module:

The Peltier TEC1-12706 is selected due to its widespread availability, its ability to efficiently generate a temperature difference when powered, making it ideal for cooling application. It offers a compact size, operates on low voltage (12V), and provides a reliable cooling capacity. The dimension of the Peltier module is 40mm x 40 mm.

b) Acrylic Sheet & Thermocol

Acrylic sheets are used for the body because they are lightweight, durable, and easy to work with. They provide good thermal insulation, are visually appealing with a polished finish. Thermocol is used as insulation to minimize heat transfer between the internal cooled space and the external environment. Acrylic sheet of 4mm thickness and thermocol of 2cm thickness is used for this purpose.

c) Heatsink & Cooling Fan

Heatsink is used to dissipate heat effectively from the hot side of the module, ensuring efficient cooling and preventing overheating. The cooling fan accelerates air circulation, preventing overheating and ensuring the Peltier module operates efficiently for effective cooling. The heatsink used on hot side of Peltier module is of 100mm x 100mm and the one on cold side is of 75 mm x 50mm.

d) Digital Thermometers/Thermocouple:

Two thermocouples are used for each refrigerator one to monitor the temperature in the refrigerator as well as to monitor the ambient temperature.

e) Power supply:

An SMPS (Switched-Mode Power Supply) of 12V 10A is used to provide a stable and sufficient power supply. The Peltier module requires a high current (up to 6-10A) at 12V for optimal performance, and an SMPS ensures energy efficiency, reliability, and protection against voltage fluctuations.

D. Methodology:

Initially, the acrylic sheets were measured and divided into six panels comprising four sides, a top, and a bottom, according to the specifications of the refrigerator. Subsequently, the thermocol sheets were cut to correspond with the dimensions of the acrylic panels. These thermocol sheets were then affixed to the inner surfaces of the acrylic panels using an adhesive. The final step involved assembling the panels with acrylic glue, resulting in a robust and airtight seal.

Fig. 2. Fabricated Box

The assembly of the Peltier module was completed by attaching the heat sink and fan assembly to the Peltier module, thereby facilitating efficient cooling. The entire assembly underwent testing to verify its functionality and performance.

The Peltier module assembly is then installed in the refrigerator models, and all wire connections are completed to connect the Peltier assembly to the power source. The final checkup ensures that there is no air leakage, and the setup's finally tested to ensure that it works and operates properly.

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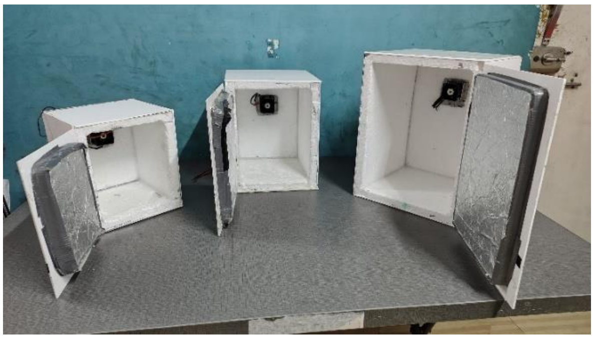

Fig. 3. Assembly of Peltier Module in Refrigerator

III. CALCULATIONS AND TESTING

A. Calculations:

The following section details the theoretical calculations used to determine the heat absorbed by the Peltier module and the time required to reach the target temperature.

Heat absorbed by Peltier module is given by:[5]

$Q\_C = \alpha\ Tc\ I - 1/2\ I^2\ Rm - km\Delta T$…………..(1)

α = Device Seebeck Voltage

= Vmax / Th

= 12/323

= 0.037 v/k

Th = 50^o C = 50 +273

= 323 K

Tc = Th – Tmax = 50 – 66 = - 16^o C + 273 = 257 K

Δ T max = 66^o C = 339 K

I max = 6 amps

Vmax = 12 V

Rm = Device Electrical Resistance

= [(Th - Δ T max) Vmax] / (Th x Imax)

= [(323 – 339) x 12] / (323 x 16)

Rm = - 0.0990 ohms

Km = Device Thermal Conductance

= [(Th – Tmax) x Vmax x Imax] / (2 x Th x Δ T max)

= [(323-339) x (12x6)] / (2x 323 x 339)

= - 5.2604 x 10 -3 W/K

Substituting all the values in equation (1);

Qc = (0.037 x 6 x 257) – (0.5 x 62 x (-0.0990)) – [(- 5.2604 x 10 -3) x 66]

= 57.054 + 1.782 + 0.347

Qc = 59.183 W

Input = 12 x 6 = 72 W

COP = Qc / Input = 59.183/72 = 0.821 = 82.1%

COP is 82.1 % (COP for Peltier Module)

Ta = 30^o C

Tc = 10^o C

Cp = 840 J/kg °C

Q = mc Δ T

= 0.38 x 840 x (30-10)

Q = 6384 J

Time = 6384/59.183 = 107.86 sec

Temperature (°C)	Time (sec)
20	53.93
15	80.90
10	107.86
5	134.83
0	161.80
-5	188.77

This table shows the relationship between temperature (in °C) and the corresponding time (in seconds) required to reach that temperature using a Peltier module

B. Testing Procedure:

We conducted a comprehensive evaluation of all refrigerator models, subjecting each unit to a 30-minute testing period. Throughout the testing process, we maintained a constant voltage of 10.5 V to ensure consistent conditions. Additionally, we carefully matched the ambient temperatures prior to testing to obtain accurate and reliable results. We meticulously recorded the temperature change per minute for each model and compiled the data into a comprehensive table for efficient analysis.

C. Test Setup:

The figure depicts the experimental setup for evaluating three refrigerator models, enabling a comparative analysis of their operational characteristics.

Fig. 4. Test Setup of Refrigerator

IV. ANALYSIS OF TESTING

A. Result:

This table provides temperature vs. time data for three refrigerator models (Small, Medium, and Large). The data shows how the temperature changes over time (in minutes) for each model, starting from the initial temperature.

Time (Min)	Temperature for Small Refrigerator	Temperature for Medium Refrigerator	Temperature for Large Refrigerator
0	29.7	29.3	29.5
1	25.3	27.2	27

Time (Min)	Temperature for Small Refrigerator	Temperature for Medium Refrigerator	Temperature for Large Refrigerator
2	21.8	24.6	25
3	19.6	23.1	23.7
4	18.6	22.2	23
5	17.6	21.8	22.4
6	17.2	21.4	22
7	16.6	21.2	21.9
8	16.2	21	21.6
9	15.9	20.9	21.4
10	15.6	20.9	21.3
11	15.5	20.9	21.3
12	15.3	20.6	21.3
13	15.2	20.5	21.2
14	15	20.4	21.1
15	14.9	20.2	21
16	14.8	20.1	21
17	14.7	20	20.9
18	14.7	20	20.9
19	14.6	20	20.9
20	14.6	19.9	20.8
21	14.5	19.9	20.8
22	14.5	19.8	20.8
23	14.3	19.8	20.8
24	14.4	19.7	20.7
25	14.3	19.7	20.7
26	14.3	19.7	20.6
27	14.3	19.7	20.6
28	14.2	19.7	20.6
29	14.1	19.6	20.6
30	14	19.6	20.5

A graph can be generated from this data to analyze the Peltier module cooling characteristics across the three refrigerator models, facilitating a comparison with prior theoretical calculations.

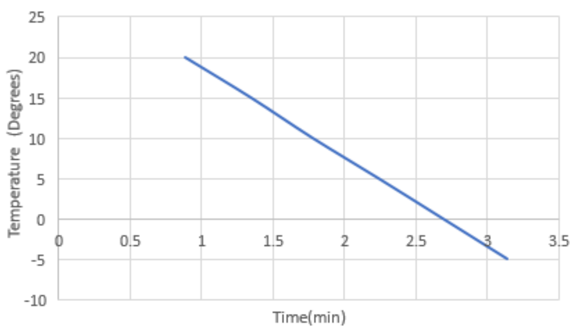

Fig. 5. Temperature vs Time (Theoretical)

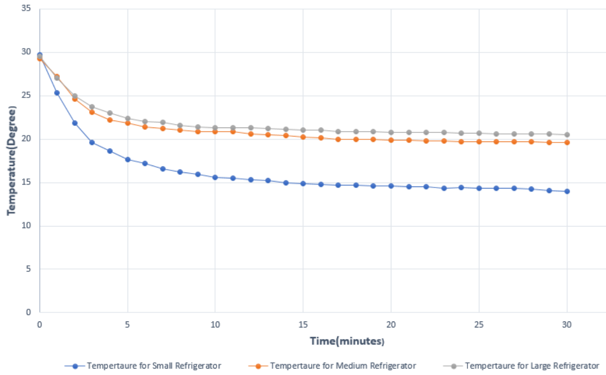

Fig. 6. Temperature vs Time for all Refrigerators

V. CONCLUSION

The theoretical graph of a Peltier Module exhibits a linear pattern, while the actual graph shows a non-linear pattern. The theoretical calculations show the time required for cooling, without considering the volume. The actual graph shows a sudden temperature drop at a high rate during start-up and a constant rate after a point. The graph of all refrigerators reveals that volume affects cooling for a given time. Small refrigerators reach the lowest temperature, while large refrigerators reach the highest. A 1% increase in volume leads to a change of 0.015 to 0.09 degrees Celsius in lowest cooling temperature for 30 minutes.

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