Assessment of a Mini Refrigerator with Thermoelectric Cooling

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Abstract:
The objectives of the present study was to design, realize and develop a mini thermoelectric refrigerator based on Peltier effect. The cooling system with interior volume of 5L that utilizes the refrigerate and maintain a selected temperature from 5 °C to 25 °C. The design requirements are to cool this volume to temperature within a time period of 6 hrs and provide retention of at least next half an hour. The design requirement, options available and the final design of Thermoelectric refrigerator for application are presented. The heat load can directly affect the performance of the refrigerator. Different heat loads are tested with the thermoelectric refrigerator.
Under the designed conditions, an optimum performance COP of 0.33 was obtained. This is completely eco-friendly refrigirator multipurpose and portable.

Key words*: Thermoelectric Cooling, Peltier effect, Mini Refrigerator.*

1. INTRODUCTION

In conventional refrigeration systems, a compressor and a freon are used to transfer heat, Mayank et al. (2012). Because of the increasing demand for cooling, this resulted in the production of more electricity and thus the production of harmful gases for the environment such as carbon dioxide, which is one of the causes of global warming Rahman et al. (2020). Thermoelectric coolers are a modern solution to the problem of refrigeration as they do not need a compressor or working fluid and are free of moving parts, Young et al. (1992). Thermoelectric coolers are made of semiconductor materials. When an electric current pass, one surface becomes cold and the other hot. This is called the Peltier effect, Sujith et al. (2016).

The Peltier Effect is the principle on which thermoelectric coolers operate. As heat is transferred from one junction to another when an electric current pass, Akash et al. (2019). Electrons move from a low-energy (p-type) semiconductor to a high-energy (n-type) semiconductor, forming a cold junction. As for when electrons move from high energy (n-type) semiconductors to low energy (p-type) semiconductors, Manoj et al. (2012). Elavarasan et al (2018), with intended to design a refrigerator with a capacity of 40 liters, designed dimension (35cm x 35cm x 35cm). The design required temperatures to reach a range of 3 ° C to 21 ° C. It is also required to reach this range in a reasonable period of time and to maintain this degree at least half an hour. A 2-liter tank of water was used to cool the heat sink. According to the study, if the outside temperature is 30 °C, the temperature reaches 10 °C inside the refrigerator. This study did not present any laboratory results but it was stated that all design conditions were fulfilled. Cassandra et al (2018), with submitted research to design a thermoelectric cooling refrigerator, two sets of thermoelectric coolers. Each set contained three panels of thermoelectric coolers 40 x 40mm. A current control processing unit model H60 CPU was used to increase heat dispersion from the hot side. Refrigerator dimensions 17.5 x 12.5 x 11.5 cm. The walls of the refrigerator were made of a corrugated layer of silicone. The design enables to reach a temperature of -2 °C in 115 minutes. Amit et al. (2016), introduce a project aimed at creating an electro-thermal refrigerator suitable for preserving medicines at a temperature of 13-8 ° C. Two sets of thermoelectric coolers have been used, which include fans and heat sinks. The refrigerator is made with dimensions of 30 x 28.5 x 22.5 cm, with walls made of a thick layer of polyethylene expanded on the outside and a thin layer of aluminum on the inside. The laboratory results mentioned in the research showed that the temperature inside the refrigerator reached 21.1 ° C within 45 minutes. But it was mentioned in the conclusion of the research that the goals were all achieved. It may have taken a longer time to reach a temperature of 13 degrees Celsius, Diana et al. (2018).

Thermoelectric coolers can be used to make small sized refrigerators. Unlike compressed vapor refrigerators with large volumes that operate with a compressor and use environmentally harmful liquids, thermoelectric refrigerators only need electricity, which can be provided from solar energy or any other source. The small size of the refrigerator makes it suitable for placing in the car or on the office as well as it runs quietly. The main purpose of the thermoelectric refrigerator is to cool within an acceptable period of time. The paper aims to design, manufacture and test a thermoelectric mini refrigerator.

2. The design of the thermoelectric mini refrigerator

The following criteria must be observed in the design of the refrigerator:

- The refrigerator should be small to be easy to carry and place in the car or office.
- The refrigerator must work efficiently and the temperature inside the refrigerator reach at least 15 °C.
- The refrigerator should cool within a reasonable period of time.
- The refrigerator must work with more than one power source (solar panels and electricity).
- The refrigerator should hold a good number of things.
- The outside of the refrigerator should be beautiful.

Based on these criteria, the refrigerator was designed and manufactured. According to requirements, the refrigerator designed with a small capacity to suit its use in the car and to suit the cooling capacity of the thermoelectric coolers. The refrigerator door preferred to place on the top to suit for use inside cars. Refrigerator outer Dimensions = 285 x 190 x 160 mm. Using solid work software to create an initial design of the refrigerator as shown in Figure 1.

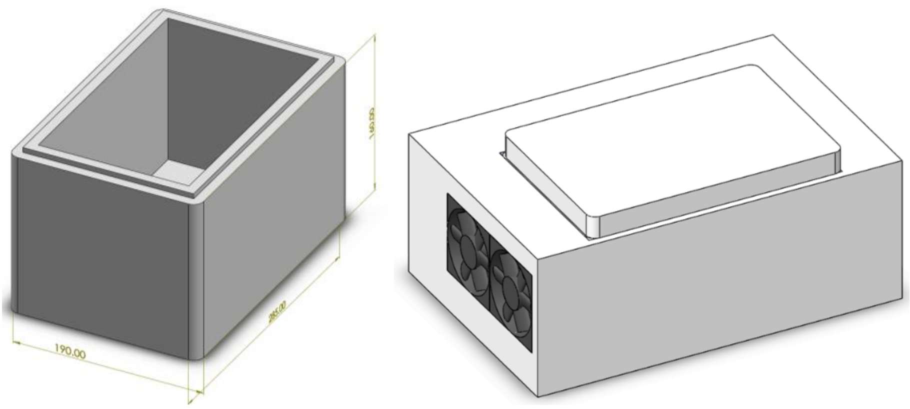

Figure.1 The mini refrigerator design

The design of the refrigerator and the determination of the number of heat coolers needed to cool the refrigerator to a temperature of at least 15 ° C needs to calculate the convection and leakage of heat through the walls and the heat leaked due to opening and closing the refrigerator door.

Calculate the internal volume of the refrigerator (V):

$$V = L.W.H \tag{1}$$

Where, L, W and H are the length, the width, and the height of the refrigerator, respectively.

The heat escaping through the walls (front, side, and top):

The front:

$$Q_{Front} = \frac{A_{Front} \times \Delta T}{\sum R_{th}} = \frac{A_{Front} \times \Delta T}{\frac{1}{h_i} + \frac{1}{h_o} + \frac{t_{Wool}}{k_{EPS}} + \frac{t_{Wool}}{k_{wood}}} \tag{2}$$

The side :

$$Q_{Side} = \frac{A_{Side} \times \Delta T}{\sum R_{th}} = \frac{A_{Side} \times \Delta T}{\frac{1}{h_i} + \frac{1}{h_o} + \frac{t_{EPS}}{k_{EPS}} + \frac{t_{Wood}}{k_{Wood}}} \tag{3}$$

The top,

$$Q_{Top} = \frac{A_{Top} \times \Delta T}{\sum R_{th}} = \frac{A_{Top} \times \Delta T}{\frac{1}{h_i} + \frac{1}{h_o} + \frac{t_{EPS}}{k_{EPS}}} \tag{4}$$

Where,

ΔT: The difference between the temperature inside and outside the refrigerator

A: The Area of refrgrator (front,side,and top)walls

h: Convection coefficient of wall

k_{EPS}: Thermal conductivity of expanded polystrene

k_{Wood}: Thermal conductivity of wood

t_{EPS}: Thikness of EPS wall

t_{Wood}: Thikness of wood wall

The sum of the heat escaping from the various walls of the refrigerator will be:

$$Q\_P = 2Q\_Front + 2Q\_Side + 2Q\_Top \tag{5}$$

There is another type of load caused by opening and closing the refrigerator door called infiltration calculate it using the following equation:

$$Q_o = \rho_{Air} \times C_{p\,air} \times n \times \frac{V}{3600} \times \Delta T \tag{6}$$

Q_o: The heat lost due to opening and closing the refrigerator

n: The number of times the refrigerator door is opened per hour (assume 4 time per hour)

ρ_{Air}: The density of air

Cp_{air}:The heat capacity of air

The last type of thermal load affecting the refrigerator is the effective load, which is the carrying of materials that are inside the refrigerator and to be cooled. There are endless possibilities of what could be inside the fridge so there is no set value for an effective load assuming that the refrigerator is full of water.

$$Q_A = m \times C_{p\,w} \times \Delta T = \rho_w \times \frac{V}{3600} \times C_{p\,w} \times \Delta T \tag{7}$$

Where,

Q_A: Active load

ρ_w: Density of water

Cp_w: The heat capacity of the water

Therfore, the cooling load Q_c will be the sum of the three loads:

$$Q_c = Q_T + Q_o + Q_A \tag{8}$$

Therfore the number of heat coolants needed for use inside the refrigerator is expressed by the following relation:

$$NO.\ of\ TEC's = \frac{1.25\ Cooling\ load\ Q_c}{Cooling\ power} = 3.2\ \approx 4\ TEC's \tag{9}$$

3. Results:

In this project, we work to measure the heat load in the refrigerator and calculate how fast the cooling is at each specific heat load, for example (the number of water bottles). At each specific capacity, we notice a different reading at a different time. We did these measurements using a heat transfer device.

In the first time of this experiment, we put one 200 ml can of water and it reached the required temperature (5.3 to 5.7 degrees Celsius) within 2342 seconds, which is equivalent to 39, minutes as shown in figure 2a.

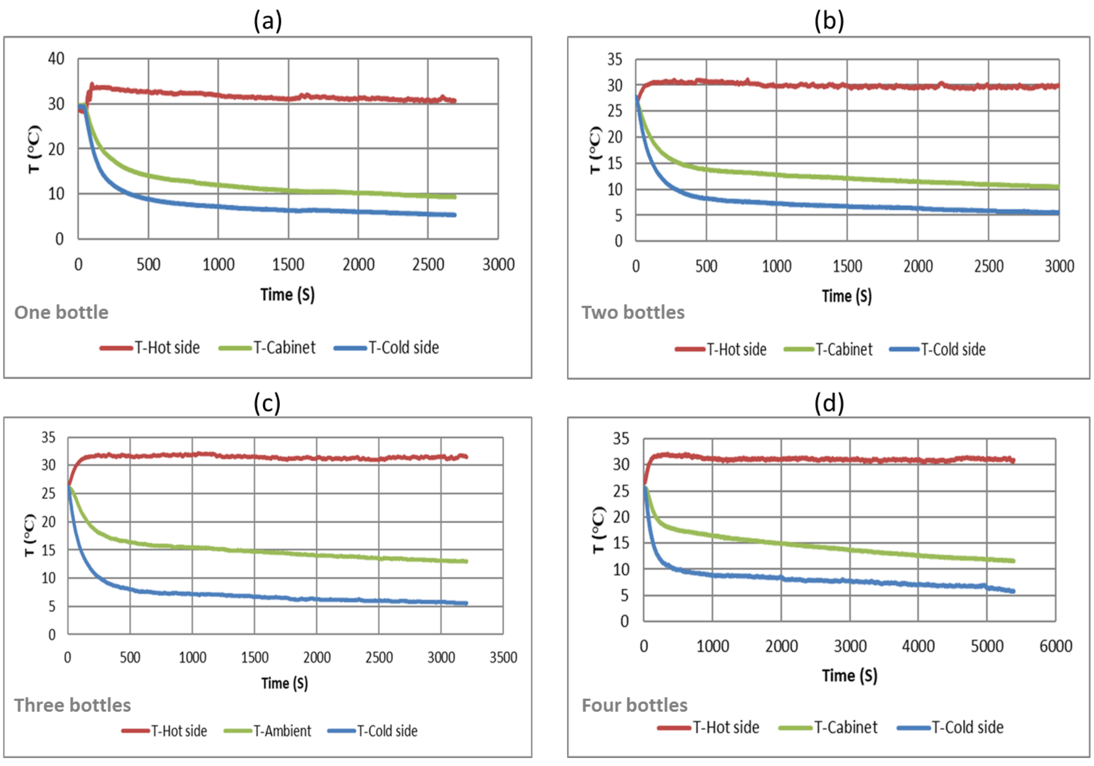

Figure. 2 Temperature diagram of hot and cold surface under three kinds of heat loads

In the second time, we added an additional load, which became two bottles of water with a capacity of 200 ml, and we noticed that the required cooling period took more time than the one before it, which took 3018 seconds (50 minutes), minutes as shown in figure 2b.

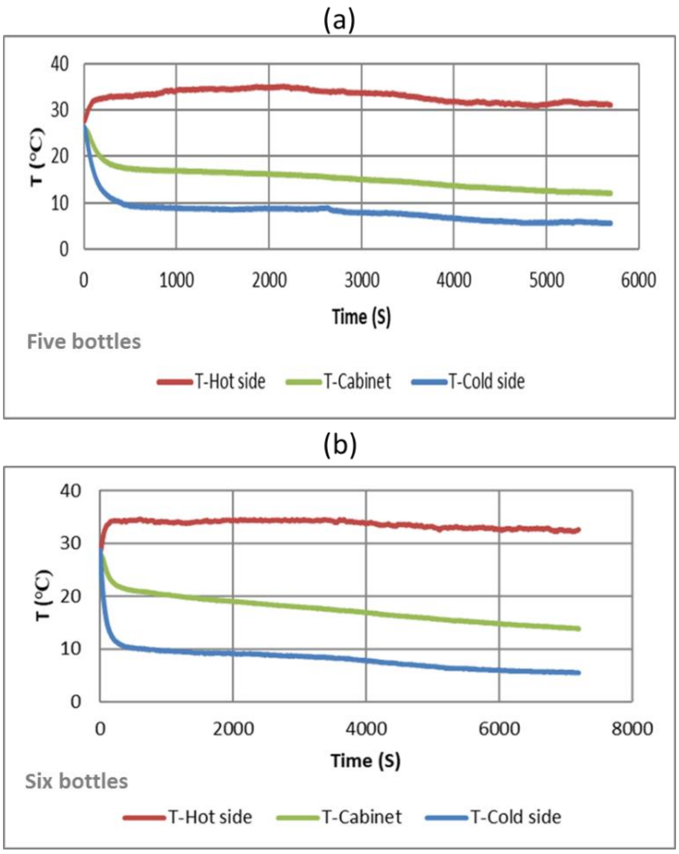

Figure. 3 Temperature diagram of hot and cold surface under three kinds of heat loads

After that, we put three bottles of water with a capacity of 200 ml, and we noticed that it reached the required temperature within 3206 seconds (53 minutes), which was close to the previous reading, minutes as shown in figure 2c.

In the fourth time, the load was increased to 4 bottles of 200 ml water, and the required temperature was reached at 5388 seconds, equivalent to 89.9 minutes. It took more time than the previous one, minutes as shown in figure 2d.

After that, 5 bottles of 200 ml of water were placed, and it took 5700 seconds to reach the required temperature, equivalent to 95 minutes, which was close to the previous reading, minutes as shown in figure 3a.

In the last time, we put 6 bottles of 200 ml of water, and at 7192 seconds the required temperature was reached, which took 119.8 minutes. As we note that when the load increases, it takes time to reach the required temperature, and this means the more the load increases, the time increases, minutes as shown in figure 3b.

Figure 4 shows a comparison of the six test results in terms of the time required for each test to reach a temperature of (5.3 to 5.7℃).

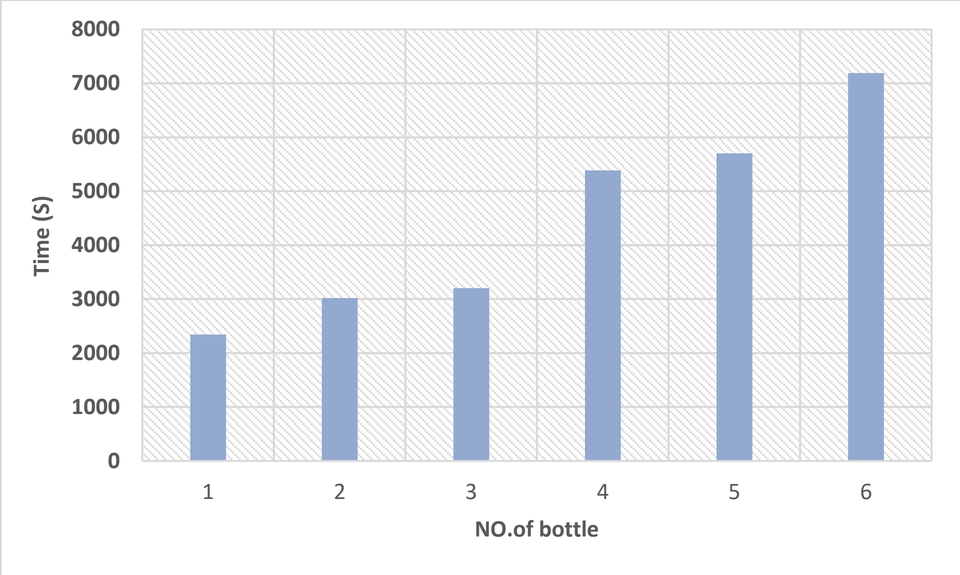

Figure 4. Comparison of the six test results

The time required to reach temperature 5.7℃ increases as the number of bottles increases. The increase in time was slight in the number of bottles from 1 to 3, and then there was a significant increase in time at bottle number 4 after that, the time continued to increase on bottles number 5 and 6.

The coefficient of performance of the thermoelectric refrigerator is very low, where the maximum COP of thermoelectric refrigerator is around 0.65.

Calculate the coefficient of performance COP:

$$COP = \frac{Q_{actual}}{Q_e} \tag{10}$$

$$Q_{actual} = \frac{m \times C_p \times (T_1 - T_2)}{t} \tag{11}$$

Q_{actual}: Actual heat removed

Q_e: Energy supply

m: The mass of the water

Cp_w: The heat capacity of the water

T_1: Temperature before cooling

T_2: Temperature after cooling

t: Time taken to change temperature from T_1 to T_2

Figure 5 shows the laboratory results of the COP calculation for the thermoelectric refrigerator for the six experiments.

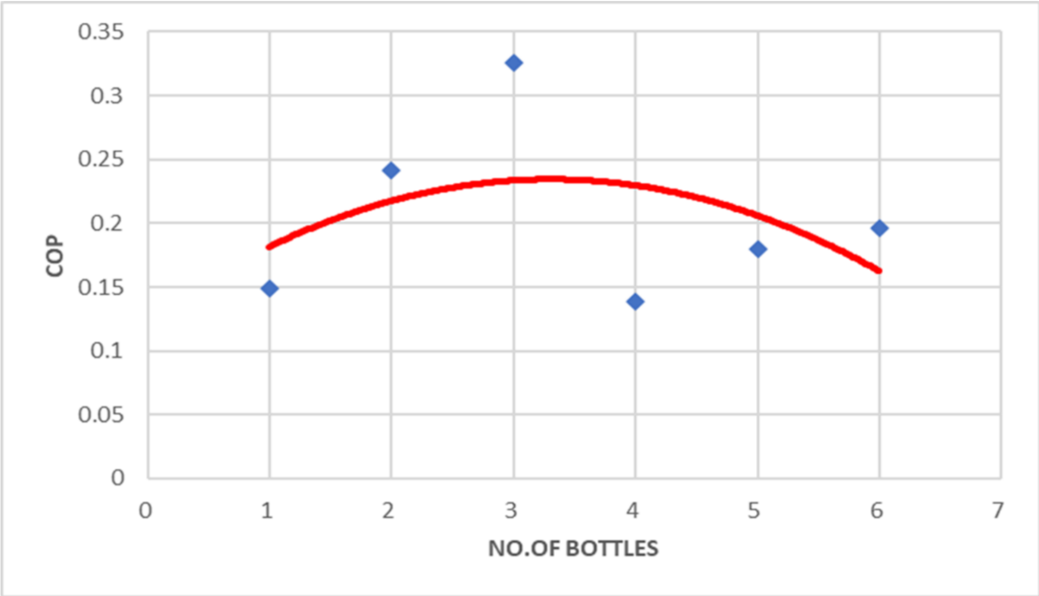

Figure 5. Comparison of thermoelectric refrigerator performance under different loads

The curve begins to rise gradually and then returns to descend. The highest COP value was on the third test with a value of 0.33. The experimental results were found that an optimum value of heat load was observed from the Figure 5. This optimumum load correspond to three water bottles.

4. Conclusion:

A mini thermoelectric Peltier cooler was designed and built in this study. The Peltier thermoelectric cell was sandwiched between an external and internal heat sinks that acted to remove heat from the cooler box. When the Peltier thermoelectric cell connected to an external power source, the Peltier effect caused the heat from the refrigerator internal space to be conducted and removed to the ambient. The mini thermoelectric refrigerator was tested under various conditions where different heat loads are tested. The heat load can directly affect the performance of the refrigerator. The results show that when the load increases, it takes more time to reach the required temperature. The experimental results were found that the Peltier cooler was able to produce COP higher than 0.33 which the output was quite high compared to previous studies. This cooler was able to lower cooler box temperature down to 13.5 °C from the ambient temperature. The mini refregirator is suitable for the preservation of drugs and medication that should be stored at cool temperature range between 15 to 8°C.

Nomenclature	
A	*The Area of refrgrator (front,side,and top)walls*
Cp_{air}	*The heat capacity of air*
h	*Convection coefficient of wall*
$kEPS$	*Thermal conductivity of expanded polystrene*
k_{Wood}	*Thermal conductivity of wood*
m	*The mass of the water*
n	*The number of times the refrigerator door is opened per hour (assume 4 time per hour)*
Q_o	*The heat lost due to opening and closing the refrigerator*
Q_A	*Active load*
$Qactua$	*Actual heat removed*
Qe	*Energy supply*
t_{EPS}	*Thikness of EPS wall*
t_{Wood}	*Thikness of wood wall*
$T1$	*Temperature before cooling*
$T2$	*Temperature after cooling*
Δt	*Time taken to change temperature from T_1 to T_2*
ΔT	*The difference between the temperature inside and outside the refrigerator*
ρ_{Air}	*The density of air*
ρ_w	*Density of water*

References

Amit Choudhary, Piyushkant Pathak, Rajat Kumar, Tushar Bsihnoi, & Vaibhav Choudhary "Design and Fabrication of Mini Eco-Friendly Refrigerator" Ideal Institute of Management & Technology, Ghaziabad (2016).

Akash Jaiswal, Ankit Dadhaniya, Jaimin Mistry, Vatsal Thakore, M/s. Neelam Bhoi "Peltier based Air Conditioner" International Research Journal of Engineering and Technology (IRJET) (2019).

Cassandra Beck, Joshua DiMaggio, Ryan Gelinas, & Zachary Wilson "Portable Thermoelectric Refrigerator" California Polytechnic State University (2018).

Diana Enescu "Thermoelectric Refrigeration Principles" Intech Open (2018).

Elavarasan , Saravanan , Abhishek Kumar , Anaitullah , Ashok Sah &Karan Kumar "Design and Fabrication of Mini Refrigerator with Thermoelectric Cooling" International Journal of Engineering Research & Technology (IJERT) (2018).

Mayank A. and Mali K V. Design and Development of Thermoelectric Refrigerator. International Journal of Mechanical Engineering and Robotics Research India (2012).

Manoj S. Raut "Thermoelectric Air Cooling for Cars" International Journal of Engineering Science and Technology (IJEST) (2012).

Rahman S.M.A., Ahmed Amine Hachicha, Chaouki Ghenai, R. Saidur, Zafar Said "Performance and life cycle analysis of a novel portable solar thermoelectric refrigerator" Case Studies in Thermal Engineering (2020).

Sujith G, Antony Varghese, Ashish Achankunju, Rejo Mathew, Renchi George, & Vishnu V "Design and Fabrication of Thermoelectric Refrigerator with Thermosiphon System" International Journal of Scientific Engineering and Applied Science (IJSEAS) (2016).

Suwit Jugsujinda, Athorn Vora-ud, Tosawat Seetawan "Analyzing of Thermoelectric Refrigerator Performance" 2ndInternational Science, Social-Science, Engineering and Energy Conference (2010).

Young, Hugh D., University Physics, 7th Ed., Addison Wesley, (1992).