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Design and Manufacturing of Thermoelectric Mini Portable Refrigerator using Autodesk Fusion 360 and Additive Manufacturing

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***Abstract:** The objective of this project is to develop portable thermoelectric refrigeration whose casing is designed using Autodesk Fusion 360 and manufactured by 3D printing. This refrigerator consists of thermoelectric module as cooling generator along with insulated cabin, thermostat and charging unit. Thermoelectric elements perform the same cooling function as Freon-based vapour compression or absorption refrigerators. The design of the refrigeration is based on the principle of thermoelectric module (i.e. Peltier effect) to create a hot side and a cold side. The cold side of the thermoelectric module is used for refrigeration purposes. On the other hand, the heat from the hot side of the module is rejected to the surroundings with the help of heat sinks and fan. Based on the heat load calculations, the thermoelectric module is selected. The system is fabricated and experimentally tested for the time taken to cool to the required temperature. The results showed that the system can maintain the temperature of approximately 10 °C with minimum power consumption of 64 Watt.*

***Keywords:** Thermoelectric refrigeration, Peltier effect, mini-portable refrigerator.*

I. INTRODUCTION

Refrigeration and cooling is an important industrial process for many applications including preservation and storage of food products, dairy products, medicines, electronic devices and automobile air conditioning. There are many methods of refrigeration such as non-cyclic, cyclic based on thermodynamic cycles and thermo-electric.

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The conventional refrigeration methods such as vapour compression and vapour absorption refrigeration are detrimental to environment. Many researches are being carried out to find out alternate methods of refrigeration to avoid environmental pollution. Thermoelectric cooling uses Peltier effect to create a heat flux between the junctions of two different types of materials. This effect is commonly used in camping and portable coolers and for cooling electronic components and small instruments [1]. Magnetic refrigeration, or adiabatic demagnetization, is a cooling technology based on the magneto caloric effect [2]. Thermo acoustic refrigeration uses sound waves in a pressurized gas to drive heat transfer and heat exchange [3]. Many Stirling cycle heat engines can be run backwards to act as a refrigerator and therefore these engines have a niche use in cryogenics [4]-[5].

Many researchers reported about the Peltier thermo-electric refrigeration system. This thermo electric cooling system has many advantages such as small size, less weight, no refrigerant and moving parts such as compressor and can be operated using DC power supply. This system finds application in portable refrigerator and ice boxes, cooling of beverage can and picnic baskets, cooling for laser diodes, blood analysers, integrated circuit chips and industrial temperature control [6]-[7]. Elavarasan E et al [8] developed a mini thermo-electric refrigerator with a capacity of 40 litres to maintain the temperature between 3^{o}C to 23^{o} C for the duration of half an hour. Prashant G. et al [1] developed a portable thermo electric refrigeration system for medical application which can achieve 40% to 60% of cooling effect as compare to conventional refrigerator. Murat Gökçek and Fatih Şahin [9] used a commercial refrigerator with 0.063 m^3 capacity as water cooled thermo-electric refrigerator and reported that high coefficient of performance can be achieved with a suitable heat sink.

A mini bovine embryo freezer of one cubic feet capacity weighing 15 kg of ModelR206 is available for some biomedical applications which use liquid nitrogen [10]. Ahmet Çağlar [11] tested a thermo electric refrigerator varying the parameters such as fans speed, power of the Peltier device as well as temperature and optimized the operating conditions to achieve the maximum coefficient of performance. Wilson R.Nyemba et al [12] developed a portable prototype thermo electric refrigerator for the total cost of the product of $129.

It is reported that though the coefficient of performance is low, it is able to achieve the temperature of vaccines between 2°C – 8°C with the minimum temperature of 6°C achieved in 5 hours from an ambient temperature of 23°C. Selvam.C et al [13] conducted numerical studies and reported that the Peltier cooler with phase change material showed significant reduction in temperature under the electric square pulse condition.

Martinez.A et al [14] reported that increasing the voltage decreased the time required to lower the interior temperature and it is mentioned that for 24 V, the time taken to reduce the temperature to 10°C is 49 minutes and it is also compared with the computational model. Suwit Jugsujinda et al [15] developed a thermoelectric refrigerator of size 25 × 25 × 35 cm^3 and reported that one hour is the time taken to reduce the temperature from 30°C to 20°C.

There is very little development of the prototype thermo electric refrigerators and the size and capacity of the thermoelectric refrigerator are generally large. Also the time taken to reduce the temperature is too long. Sometimes the medical fraternity may need a smaller version of thermo-electric refrigerator and less time to reduce the temperature of the cooling chamber. This paper explains about the development of a mini portable thermoelectric refrigerator whose body is manufactured using additive manufacturing and designed by Autodesk Fusion 360.

II. SCOPE OF THE RESEARCH WORK

The project aims to design and develop a lightweight, easy-to-operate, portable cylindrical refrigerator box using thermoelectric refrigeration which is capable of maintaining the temperatures of 8 ±2 °C. The project intends to help safely store medicines while travelling or in case of any emergency situation like power-failure, environmental adversities like flood, earth-quake etc. The mini portable refrigerator is capable of setting different temperatures in the refrigerated space so the product can be used for more than one specific purposes.

III. EXPERIMENTAL PROCEDURE AND METHODOLOGY

In this research work, a cylindrical mini thermoelectric refrigerator is designed using Autodesk Fusion360. Two designs of the casing of the refrigerator are made using Autodesk Fusion 360 as shown in Fig.1a and Fig.1b. The design in Fig1b is selected for additive manufacturing. The dimensions of this casing are shown in Fig.2. The number of fins required for cooling and critical thickness of casing of the refrigerator is calculated based on the assumption of forced convection.

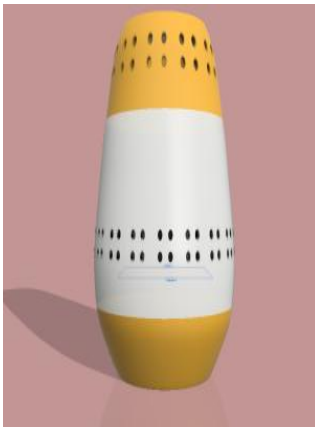

Fig.1a. Conical Casing

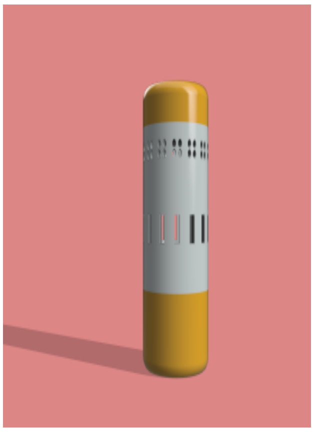

Fig.1b. Cylindrical casing

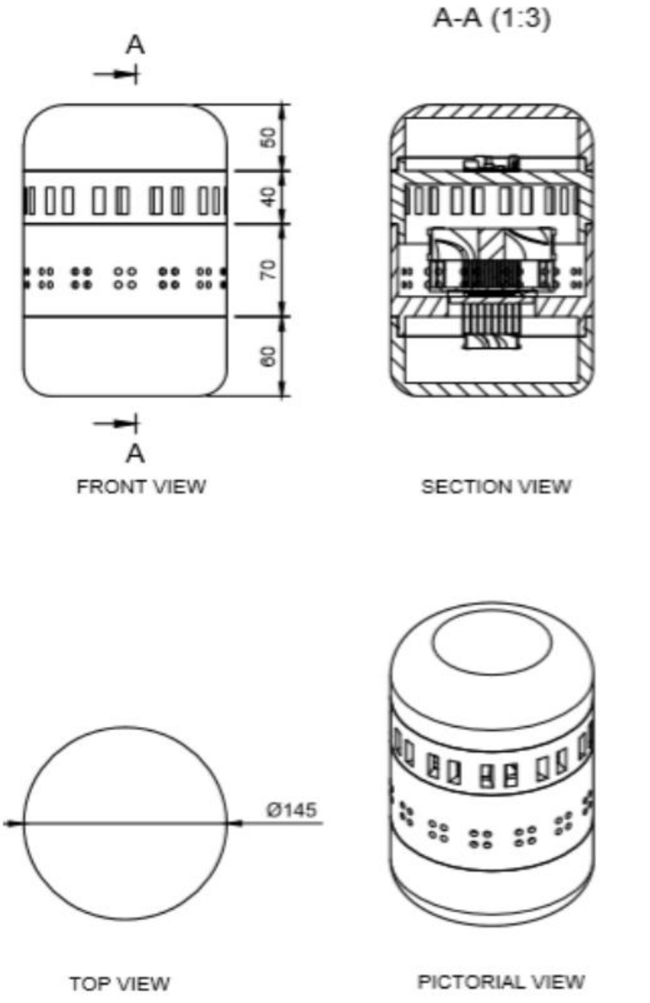

Fig.2. Dimensions and sectional view of the thermo-electric refrigerator

The various components required for this mini portable refrigerator such as thermoelectric (Peltier element TEC1-12706)) module, heat sink for cold side and hot side, fans, thermostat (W1209 digital temperature controller) for controlling the temperature of about 5 to 10°C in the refrigerator space, a 12V/5A DC power adapter for power supply are selected as shown in Fig. 3 to Fig.8 for assembling in the cylindrical casing.

The casing material used is polylactide (PLA) which is biodegradable. The casing is fabricated by 3D printing (additive manufacturing) known as fused deposition modeling (FDM). Since this manufacturing process has many advantages such as freedom to design as per the customer requirement, green manufacturing, weight savings and useful for mass production, this process is selected to fabricate the casing.

All the components are assembled in the casing and the exploded view of the refrigerator is shown in Fig.9. The insulation material "Styrofoam" is a trademarked brand of closed-cell extruded polystyrene foam (XPS), commonly called "Blue Board" is used to insulate the interior side of the wall of the casing. The circuit diagram is shown in Fig 10 for the connection of the various components of the thermo electric refrigerator.

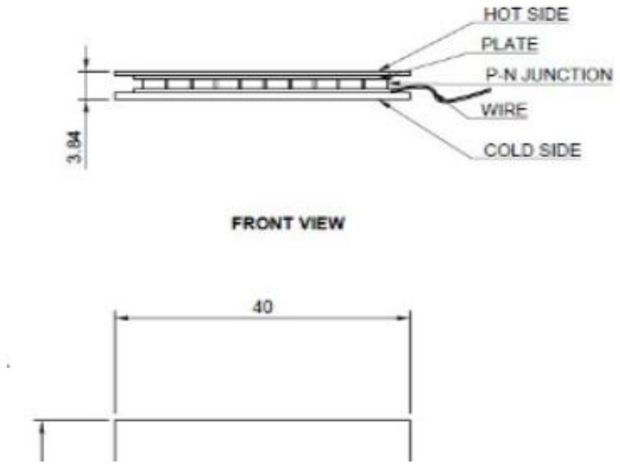

Fig.3. Peltier module

The assembly is tested for the effectiveness of cooling and maintenance of required temperature with and without the insulation. The same assembly is tested after housing it inside the cylindrical casing.

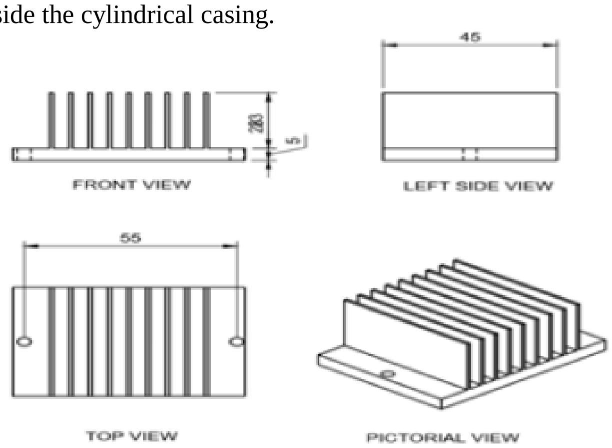

Fig.4. Cold side fin

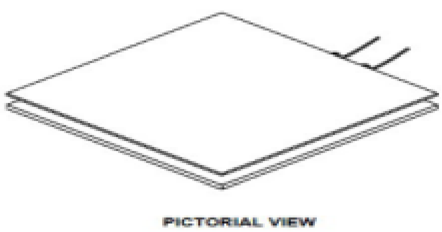

Fig.5. Hot side fin

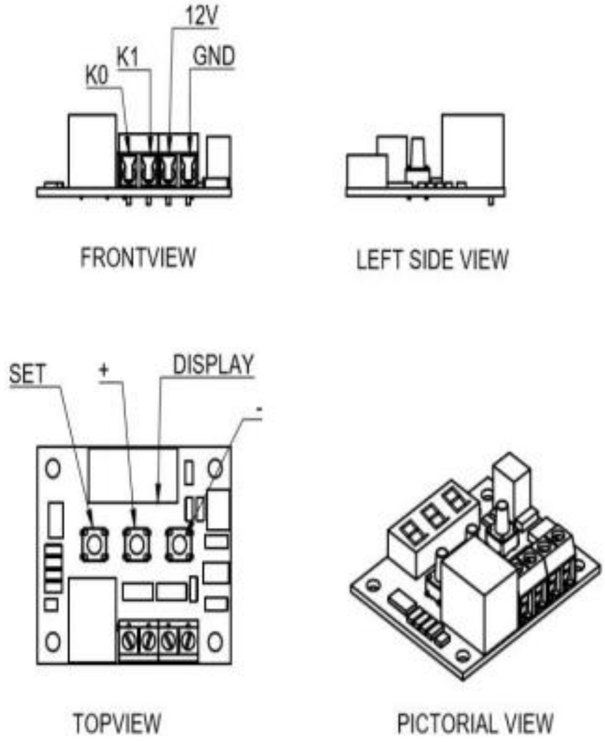

Fig.6. W1209 Thermostat

Fig.7 Exhaust fan

Fig.8. 12V, 5A DC power adapter supply

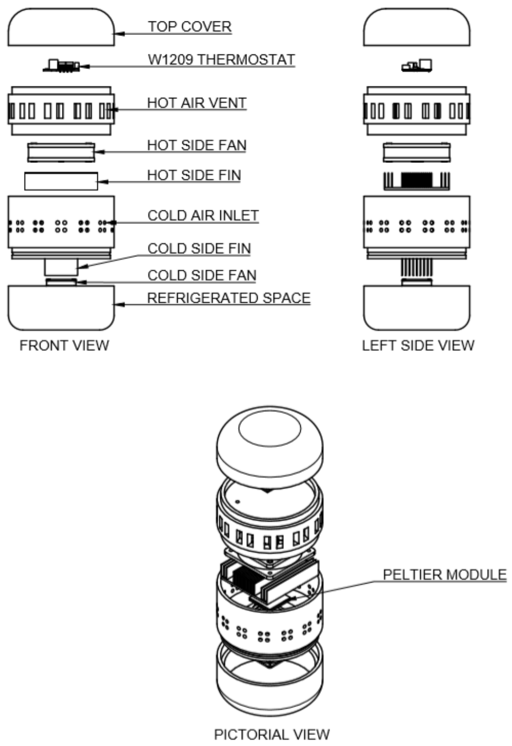

Fig.9. Exploded view of portable mini refrigerator

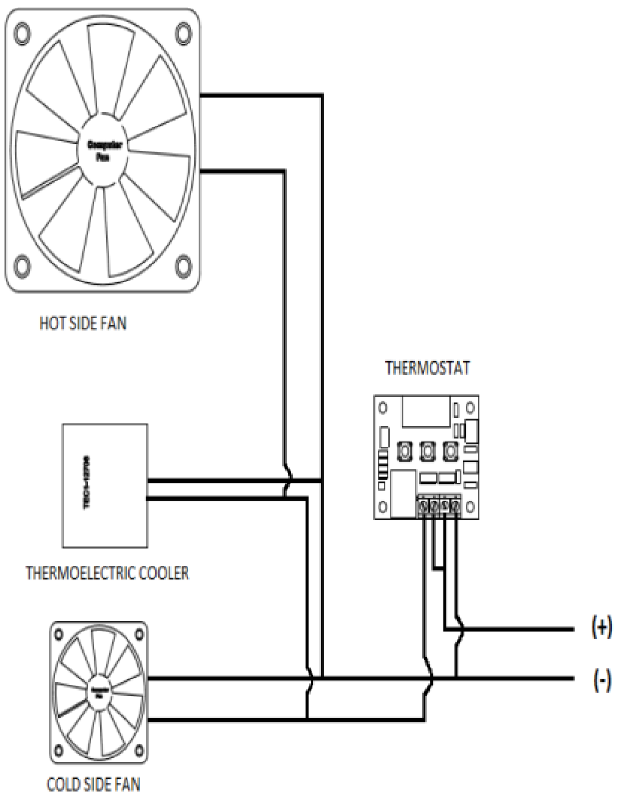

Fig.10. Circuit Diagram

IV. DESIGN CALCULATION FOR NUMBER OF FINS AND CRITICAL THICKNESS OF INSULATION

A. Fin calculation for forced convection

The approximate number of fins required for efficient heat transfer in the refrigerator is calculated based on the formulae available in Ref. [16].

<u>Fin Dimensions</u>:

Length of one fin (l) = 2 mm
Width of one fin (b) = 10 mm
Thickness of one fin (y) =1 mm
Atmospheric temperature (t_a) = 32 ºC
Base temperature (t_o) = 80 ºC
Heat transfer coefficient (h) = 64 W/m^2 ºC
Thermal conductivity of material (K) = 204.2 W/m^2 ºC
Perimeter of one fin (P) = 2(b + y)
= 2(0.1 + 0.001)
= 0.202 m
Area of cross section (A_{cs}) = b × y
= 0.1 × 0.001
= 1×10^{-4} m^2

Number of fins required= Heat dissipated from Peltier/Heat dissipated from one fin (**Q_{fin}**)

$$Q_{fin}=\sqrt{PhKAcs}\,(t_o-t_a)\left[\frac{\tanh(ml)+\frac{h}{Km}}{1+\left[\frac{h}{Km}\times\tanh(ml)\right]}\right] \quad (1)$$

Where,

$$m=\sqrt{\frac{hP}{KAcs}} \quad (2)$$

P = Perimeter of fin (m)
h = Convective heat transfer coefficient (W/ (m^2 K)
K =Thermal conductivity of the fin material (W/ (mK)
l = length of the fin (m)
t_0 = Temperature at the base of the fin (K)
t_a = Ambient temperature of air (K)
Substituting the data's in Eq (1),

$$m=\sqrt{\frac{hP}{KAcs}}$$

$$=\sqrt{\frac{20\times0.202}{204.2\times1\times10^{-4}}}=14.06$$

$$Q_{fin}=\sqrt{PhKAcs}\,(t_o-t_a)\left[\frac{\tanh(ml)+\frac{h}{Km}}{1+\left[\frac{h}{Km}\times\tanh(ml)\right]}\right]$$

$$=\sqrt{0.202\times64\times204.2\times1\times10^{-4}}\times$$

$$(80-32)\left[\frac{\tanh64(14.06\times0.02)+\frac{64}{204.2\times14.06}}{1+\left[\frac{64}{204.2\times14.06}\times\tanh(14.06\times0.02)\right]}\right]$$

= 14.0581 W

Heat dissipated from Peltier = 92W as is given in the specification of the model TEC12706L in Table I [17]

∴ Number of fins required = 92/14.0581
= 6.309 = 7 fins

As per calculation 7 fins are required to dissipate about 92 W of heat.

B. Design calculations of critical thickness of insulation

A material which retards the flow of heat with reasonable effectiveness is known as insulation. Insulation serves the following two purposes.

(i) It prevents the heat flow from the system to surroundings.

(ii) It prevents the flow from surrounding to the system

In addition to the above purposes, the insulation always increases the conductive thermal resistance. The calculation of critical thickness of insulation in portable mini refrigerator is done as follow [16].

Length of the refrigeration space is, L = 6cm

Surface temperature of refrigeration space, $T_1 = 7.5^oC$

Temperature of air, $T_{air} = 28^oC$

Heat transfer coefficient at outer surface,

$h_0 = 20W/m^2{}^oC$

Thermal conductivity of insulating material,

$k=0.193W/m°C$

The rate of heat transfer (Q) from surface of solid cylinder to the surroundings

$$Q = \frac{2\pi L(T_1 - T_{air})}{\frac{\ln(\frac{r_2}{r_1})}{K} + \frac{1}{h_0 r_2}} \quad (3)$$

r_1 = 5.5cm, internal radius of the insulation

Where $\mathbf{r_2 = r_c} = \frac{K}{h_0}$ (4)

$= \frac{0.193}{20}$ = 0.965cm is the critical thickness or outer radius of insulation.

$$Q = \frac{2\pi\ 6\times10^{-2}(28-7.5)}{\frac{\ln(\frac{7}{5.5})}{0.193} + \frac{1}{20\times7\times10^{-2}}} = 3.93W$$

In this design the r_2 value is taken as approximately 1 cm (0.965cm) and the r_1 value is taken as 7cm.

V.COEFFICIENT OF PERFORMANCE

The efficiency of a refrigerator or heat pump is given by a parameter called the coefficient of performance (COP).The general measure of efficiency of a TEC is based on the amount of heat that it removes compared to the amount of work that it requires. This value is referred to as coefficient of performance, COP. In this study we use TEC1-127-06L a thermoelectric module, whose specifications are given in the Table.I.

Table- I: TEC Specification

Module: Model TEC12706L			
Q_{max}	92W	Dimensions	
I_{max}	6A	Width	40mm
V_{max}	15.4V	Length	40mm
T_{max}	138˚C	Thickness	3.6mm
Number of thermocouple	127		

The thermoelectric cooler module material chosen is Bismuth telluride. The properties of a 127 couple, 6A Bismuth Telluride module TEC1-127-06L are taken from ref [17] as follow:

Seebeck coefficient (S) = 0.01229 V/k, Module thermal conductance (K) = 0.1815 W/k, Module resistance (R) = 4Ω.

$$Q_L = -[SIT_c - (I^2R/2) - k(T_h - T_c)] \quad (5)$$

The negative sign indicates the heat rejection.

The heat transferred out of the hot side into the heat sink is given by

$$Q_H = SIT_h + (I^2R/2) - k(T_h - T_c) \quad (6)$$

COP can be calculated by dividing the amount of heat absorbed at the cold side to the input power.

$$COP = \frac{Q_L}{Energy\ supplied} \quad (7)$$

Heat absorption is calculated as below.

$Q_L = -[SIT_c - (I^2R/2) - k(T_h - T_c)]$

$= -[(0.01229\times6\times10)) - (6^2\times4\times.5) - (0.1815\times70)]$

$=83.92J$

The energy supplied based on the first law of thermodynamics is:

Energy supplied, $W = Q_H - Q_L$ (8)

$= SI(T_h - T_c) + I^2R$

$= (0.01229\times6\times70) + (6^2\times4)$

$=149.16J$

Where, COP-Coefficient of Performance

I-Current

k-Thermal conductivity

Q_H-Heat rejection

Q_L-Heat absorption

R-Electric Resistance

TEC-Thermoelectric cooler

P-Power consumption

W-Energy supplied

Temperature at hot side T_h =80˚ C, Temperature at cold side T_c =10˚ C

The Coefficient of Performance (COP) is calculated using equation (7) and its value is found to be 0.5626.

VI RESULTS AND DISCUSSION

The prototype of mini portable refrigerator casing manufactured by fused deposition modelling is shown in Fig 11. All the components of the refrigerator are assembled as shown in the exploded view in Fig.9 inside this casing. The component assembly (Fig. 12) without the casing was tested in a styrofoam insulated volume of 432 cm^3 to verify the temperature versus time to reach the required temperature.

The test results given in Fig 13 shows that in 20 minutes time the temperature attained is 18.4˚C without insulation whereas it is 10˚C with insulation. The same assembly after fixing in the casing is also tested and found to give approximately same temperature of 10^oC within twenty minutes time. It is reported that the COP for portable prototype thermo electric refrigerator is varied from 0.083[12] to 0.65 [15].

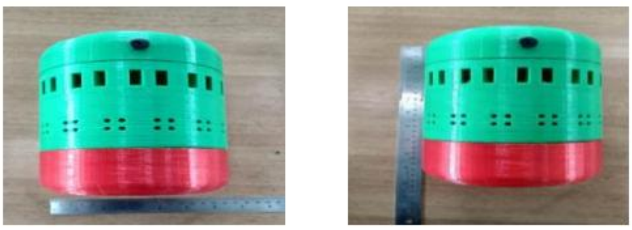

Fig.11. Cylindrical mini portable refrigerator casing.

Fig.12. Component assembly

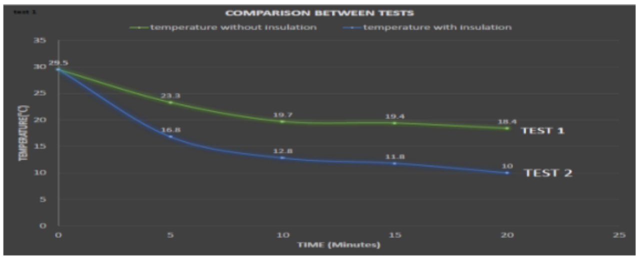

Fig.13. Temperature versus time during the refrigeration process

The total volume of space available in this refrigerator casing is about 645cm^3. With this space and refrigeration capacity it may be used for storing and transporting many medicines. The power supply is rechargeable using any power bank.

VII. CONCLUSIONS

The mini portable refrigerator is designed using Autodesk Fusion 360 and manufactured by 3D printing using polylactide material. The approximate manufacturing cost of this refrigerator is $75.

This portable refrigerator is compact, less weight, aesthetic and able to maintain the inside temperature of 8 to 10^{o}C. The COP is 0.56 and it can be used for storing medicines and other small items which needs to be maintained at this temperature.

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