Environment and Ecology 40 (2B) : 774—781, April—June 2022
ISSN 0970-0420

Solar Based Multi-Cold-Storage Chamber Model using Thermoelectric Cooling Effect

Th. Bidyalakshmi Devi, Yogesh B. Kalnar, Bhupendra M. Ghodki, Ashish Kumar Singh

Received 6 January 2022, Accepted 24 February 2022, published on 8 July 2022

ABSTRACT

A multi-cold storage chamber model was developed using Peltier module (TEC1-12706) that works on the principle of thermoelectric cooling effect. The storage chamber was made of wood and insulated with thermocol. The total dimension of the storage chamber was 0.46 m (length) × 0.46 m (width) × 0.23 m (depth) which was divided into two equal parts having $0.02m^3$ each for both control and cold compartment. Two Peltier module was used for the cold chamber whereas an exhaust fan was used for the control chamber. The system was tested by loading 2.0 kg tomato on both the compartment (cold and control). A maximum temperature reduction of 9^oC could achieve during no load condition whereas temperature difference of 8^oC was obtained for load condition. The actual COP of the cold chamber was 0.1 whereas that of control chamber was 0.9. The percentage reduction of weight of tomato after 12 days of storage was 19.05% and 26.17% for cooling and control chamber respectively.

Keywords Peltier module, Storage, Tomato, Coefficient of performance, Cold chamber.

INTRODUCTION

India ranks second in the production of fruits and vegetables in the world with 73.53 MT of fruits and 169.1 million metric tonnes of vegetables (NHB, 2015-16 Storage of fresh agricultural produce is a challenging task as they continue respiration and ripening activities/process even after harvest. Further, the deterioration rate increases due to presence of high moisture content (80-90%) in fresh produce. It is estimated that, in India, post-harvest losses of fruits and vegetables is 30-35% (Basediya *et al.* 2013).

Storage of the fresh horticultural produce at lower temperature could extend their shelf life. Unscientific traditional storage systems, still being practiced by the farmers, results in large scale wastage of agricultural produce during storage. Some of the ancient storage practices of fruits and vegetable include storing in wooden/bamboo huts, pits or cool dry rooms with proper ventilation on floor or bamboo racks that can

Th. Bidyalakshmi Devi*, Yogesh B. Kalnar,
Bhupendra M. Ghodki
ICAR-CIPHET, Ludhiana, 141004 Punjab, India
Ashish Kumar Singh
Student trainee, ICAR-CIPHET, Ludhiana, 141004 Punjab, India
Email: bidyala@gmail.com
*Corresponding author

store the product for few days. In developing countries, for large scale storage, mechanical refrigeration is commonly practiced (Basediya *et al.* 2013). The necessary low temperature for preservation depends on required storage time and type of stored product. In general, agricultural produce can be classified into three groups, namely, (a) food that are alive at the time of storage distribution and sale, for example, fruits and vegetables, oilseed, pulses and others, (b) food that are no longer alive for example, processed food such as processed meat and fish products and (c) food that enhance the quality after storage such as beer, tobacco and others. In all these food types, refrigeration is the most important and commonly used method to preserve and extend the shelf life.

Even though mechanical refrigeration is widely used it is expensive and energy intensive that require high initial capital investment and continuous supply of electricity. On the contrary, thermoelectric module for cooling system is highly reliable, low weight, compact size, involves no moving parts, produces less noise and require less maintenance with precise control of temperature (Elsheikh *et al.* 2014). Thermoelectric cooling works on the principle of Peltier effects which state that when a direct current is passed between two electrically dissimilar materials there is heating at one junction whereas cooling at the other junction (Suryawanshi *et al.* 2016, Lavanya *et al.* 2016, Rawat *et al.* 2013). Accordingly, the thermoelectric refrigeration is predominantly used in medical instrument, scientific equipment and other electronic devices where a high precision temperature control is necessary (Dell *et al*. 2015, Nonoguchi *et al*. 2013). However, due to low coefficient of performance (COP) and requirement of DC supply the application of thermoelectric refrigeration is restricted to low capacity.

The DC power supply require for the thermoelectric refrigeration may be supplied from solar energy. Rokde *et al.* (2017) studied the solar powered thermoelectric refrigeration system considering the need of application of renewable energy for the overall benefits. The sensors used for the system were Infra-red (IR) sensors to display on the liquid crystal display (LCD) attached outside the cooling system, temperature and humidity sensor and solar battery charging circuit to charge and supply the required power. Dhawade *et al.* (2015) reported a portable solar thermoelectric refrigerator cum cooler that provide a comparatively low cost alternative to existing cooling systems. The system is compact and portable that can be customized and fabricated to meet requirements of different users.

Basic principle of Peltier device

Thermoelectric cooler operates based on the principle of Peltier effect. Peltier effect is the cooling of one junction and the heating of the other when electric current is maintained in a circuit having two dissimilar conductors/semiconductors. The heat absorbed or released at the junction is proportional to the electric current supplied. The common application of the Peltier effect is cooling. However, it can also be used for heating or control of temperature. DC power supply is required to operate the Peltier module. Thermoelectric refrigeration is one such application of Peltier effect. Peltier found that rate of heating or cooling is directly proportional to current passing through the junction (Eq. 1).

$$Q \propto I \qquad (1)$$

where, Q = rate of heating or cooling
I = current passing through the junction

This Peltier effect can be used for refrigeration purpose. Applications for thermoelectric modules cover a wide spectrum of product areas. These include equipment used by military, medical, industrial, consumer, scientific laboratory and telecommunication organizations. Thus, for preservation of fruits and vegetables, thermoelectric refrigeration system can be used conveniently for small capacity.

Keeping the above points in view, this study aimed to design and development of storage chamber model using thermoelectric refrigeration module.

MATERIALS AND METHODS

The materials and methodology followed for manufacturing of thermoelectric refrigeration system (TER) and conducting the experiments are discussed in this section. To study the performance of the system, tomato was selected as it is highly perishable in nature.

Conceptual design of the storage unit

Design calculation and selection of material

The design of the chamber was made based on the physical property of the tomato. The true density of the tomato was 1180kg/m^3 as measured by water displacement method. The designed capacity taken for storage was 5.0 kg. Accordingly, the dimension of the storage chamber was calculated.

True density of the tomato = 1180 kg/m^3
Bulk density = 590 kg/m^3 (considering 50% porosity in bulk storage, 48.54 % porosity as reported by Kaymak *et al.* 2010)
Designed capacity = 5.0 kg
Volume required for storage = 5 (capacity)/590 (bulk density) = 0.0085m^3

Assumption:
a) Space or volume covered by module=5%
b) Space or volume for proper ventilation=50%
Therefore, total volume required for cold storage (compartment) = Volume of storage + volume covered by module + volume for ventilation
= (1+0.05+0.50) 0.0085
= 0.013m^3

Considering 1.5 times of design space for ease of connections of components and maintaining hygiene total volume required of the chamber =0.02m^3
The dimension taken for inner side of chamber = 0.44 m (length) × 0.21 m (width) × 0.21 m (depth)
= 0.02 m^3

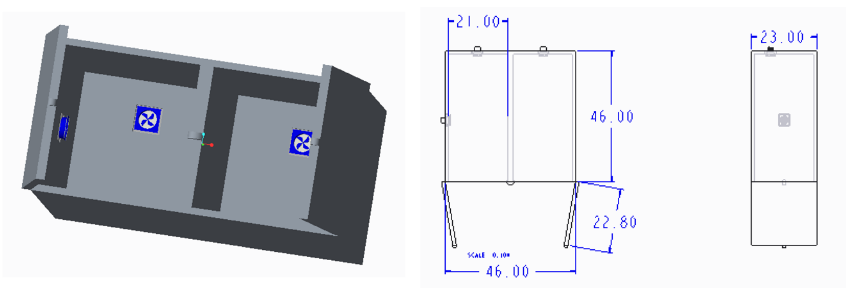
The storage unit was constructed in duplicates to study the effect of thermoelectric refrigeration for storage of agricultural produce. The storage unit was made of wood and insulated with one centimeter thickness thermocol (polystyrene) to prevent heat flow from outside environment and sandwiched between the wooden box and the aluminium sheet (purchased from local market). The storage unit was composed of two equal parts (a) cold compartment having thermoelectric module or Peltier device and (b) ventilation chamber (control unit). Therefore, the overall dimension (considering insulation) of the storage unit (wooden box) was 0.46 m (length) × 0.46 m (width) × 0.23 m (depth), that is, addition of cold and control compartment. The isometric view and the line diagram of the designed system are shown in figure below (Fig.1).

Ventilation (control) chamber

The control chamber was made only by providing an exhaust fan having 12 V and 0.20A DC power supply. The fan was fixed at the back side of the chamber for proper ventilation and to maintain a constant temperature inside the box.

Cold chamber

In the preliminary study, the reduction in temperature using one Peltier module (TEC1-12706) was 3-4 ^{o}C. Hence, the cold chamber was provided with two Peltier module (TEC1-12706) to deliver the desired cooling effect as per storage requirement of tomato. The cold side of the Peltier module was faced to the inside of chamber whereas the hot side was kept



(a) (b)

Fig. 1. (a) Isometric view (b) Line diagram (the dimensions are in cm).

towards the ambient environment. The hot side is connected with the heat sink having dimension of 0.075 m (length) × 0.08 m (width) × 0.045 m (thickness) to dissipate heat to the surrounding.

The finned surface, that is, heat sink was used to enhance and increase the rate of heat transfer from the hot surface of the thermoelectric module so that the heat will be discarded outside the chamber. In order to maintain the efficiency of the thermal module, cooling fan was used to reject the heat from the hot side of the module to ambient surroundings.

Power and sensors unit

The power required to operate the fans, thermos-electric module and sensors was supplied from 12 V solar battery. The battery was connected to two 240 W solar PV panel. The temperature and humidity of the chamber was measured using the sensor DHT22 which is a basic, low-cost digital temperature and humidity sensor.

The embedded system 'Arduino Mega 2560' was used to control and operate the fan, thermoelectric module as well as the sensor. The temperature of both the chamber was displayed in LCD.

Performance evaluation

Coefficient of Performance (COP) was calculated to evaluate the efficiency of cool chamber. COP is defined as the ratio of useful cooling provided to work required. The theoretical and actual coefficient of performance (COP) for the system was calculated. The initial and final weight of the tomato was recorded and the percentage change in weight was calculated during the storage period.

***Heat load calculation* (*for cooling chamber*)**

Assumption

1) Ambient temperature = 35 °C
2) Specific heat for tomato = 3.98 kJ/kg-°C (Anonymous)
3) Cooling chamber temperature=25 °C
4) Sample taken = 5.0 kg

Sensible heat load, (Q) = $m\ C_p \Delta T$
Change in temperature= 35 °C-25 °C=10 °C

$$Q = 5 \times 3.98 \times 10$$
$$= 199 \text{ kJ} \sim 200 \text{ kJ}$$

Considering the achievement of the cooling effects in 1 h,
Q = 55.5 W = 56 W

***Heat load calculation* (*for control chamber*)**

Assumption

1) Ambient temperature = 35 °C
2) Specific heat for tomato = 3.98 kJ/kg-°C (Anonymous)
3) Control chamber temperature =30 °C
4) Sample taken = 5.0 kg

Change in temperature= 35 °C-30 °C=5 °C

$$\text{Heat (Q)} = mC_p\Delta T$$

=5×3.98×5= 97.5 kJ =27 W (Considering the achievement of the cooling effects in 1 h)

Considering the total energy required to provide cooling effects, thermoelectric module, TEC1-12706, having 60 W rating was chosen.

***Coefficient of Performance* (*COP*)**

The theoretical COP of the system was calculated using the following formula (Francis *et al.* 2013).

$$COP = \frac{Q_C}{W}$$

where, COP = Coefficient of performance
Qc = Refrigeration effect ,
W = Input power

Refrigerating effect is given by $Q_c = (\alpha_m \times T_c \times I) - \frac{1}{2}(I^2 R_m) - K_m \times (T_h - T_c)$

Where,

α_m = Seeback Voltage = $\frac{V_{max}}{T_h}$

R_m =Electrical Resistance of PELTIER Module

$$\frac{T_h - \Delta T_{max}}{T_h} \times \frac{V_{max}}{I_{max}}$$

K_m = Thermal Conductance of Peltier Module =

$$\frac{T_h - \Delta T_{max}}{2\Delta T_h} \times \frac{V_{max} x I_{max}}{I_t}$$

Input Power is given by,

$W = \alpha_m \times I \times (T_h - T_c) + (I^2 R_m)$

For Module TEC1-12706

T_h = Temperature of hot side of PELTIER module 45˚C =318 °K [Assumption]

T_c = Temperature of cold side of PELTIER module 20˚C =293°K [Assumption]

Specification:

I_{max} = Maximum input current = 5A

V_{max} = Maximum DC Voltage = 12V

ΔT_{max} = Maximum Temperature Difference = 66° K

α_m = Seeback Voltage = $\frac{V_{max}}{T_{max}} = \frac{12}{318}$ = 0.04 V/°K

$R_m = \frac{318\text{-}66}{318} \times \frac{12}{5} = 1.9\Omega$

$K_m = \frac{318\text{-}66}{2 \times 66} \times \frac{12\times5}{366}$ =0.4 /˚K

$Qc = (0.04\times293\times5) - \frac{1}{2}(25\times1.9) - 0.4\times(318 - 293)$

= 24.85 W

Input Power is given by,

$W = 0.04026 \times 5 \times (318 - 293) + (25 \times 1.9)$

W = 52.5 W

The system was tested by loading 2.0 kg tomato on both the control and cold chamber. The change in temperature was noted for load and no load condition for both the chamber for every 30 minutes during the study.

RESULTS AND DISCUSSION

The results obtained in this study are discussed below. The study was conducted to develop a thermoelectric refrigeration model and study the cooling effects for storage of the agricultural produce. The chamber (including ventilation and cold chamber) was made of wooden box of dimension (46 × 46 × 23) cm^3 and the thermocol was provided for insulation which was then fixed with aluminum sheet.

The box was divided into two inner compartments of equal size; one compartment used for cooling purpose whereas the other one was used as control chamber (Fig.2). Two temperature and humidity sensor were connected in each compartment and accordingly the temperature and humidity were shown on the LCD display. Cooling, control and ambient temperature and humidity were taken for every 30mins interval at with and without load condition.

No load condition

Temperature of cold chamber decreased from 33.1˚C to 27 ˚C in nearly 120 minutes. The minimum temperature decreased was 26°C in 6.0 h. The comparison of the temperature for cooling chamber, control chamber and the ambient temperature are listed in the Table

Fig. 2. Multi-cold storage chamber model using Peltier module (with and without load condition).

Table 1. Variation of temperature with time in cooling, control and ambient condition in no load condition.

S. No.	Time (min)	Cooling chamber temp (°C)	Control chamber temp (°C)	Ambient Temp(°C)
1.	0	33.1	33.1	33.1
2.	30	29	32.20	32.5
3.	60	28.4	32.50	32.8
4	90	27.90	32.8	33
5.	120	27	33.10	33.40
6.	150	27.10	33.30	34
7.	180	27.10	33.50	34
8.	210	27.20	33.65	34.20
9.	240	27.10	33.8	34.20
10.	270	27	33.9	34.5
11.	300	27	34	34.7
12.	330	27.10	34.10	34.7
13.	360	27.10	33.9	34.5
14.	390	26	33.8	34.5
15.	420	26	33.8	34.3

1. Fig. 3 shows the change in temperature with time for cooling, control and ambient at no load condition.

Load condition

Temperature of the cold chamber decreased from 35° C to 27°C in nearly 120 minutes in loaded condition. Table 2 shows the variation of temperature with storage time. However, maximum temperature that could reduce in control chamber was 2.5°C in 150 mins. Fig. 3 indicates the graph between temperature of the chambers (control and cold) and ambient along with storage time. Fig.4 shows the change in temperature with time for cooling, control and ambient at load condition.

2. Change of the weight of tomato with time.

The percentage change in weight of the tomato for controlled chamber was 26.17 % whereas the cooling chamber was 19.05 % losses in weight after 12 days of storage.

Performance of the thermoelectric refrigerator

The active heat load is expressed as the equivalent cooling power that the unit will need to provide when the sample at ambient temperature is placed in the container. It was decided that 2 kg of tomato at room temperature took as the test sample .When the designed thermoelectric refrigerator was tested, it was

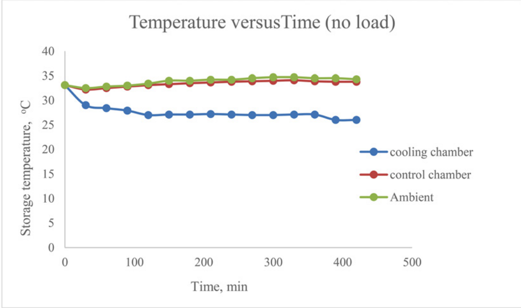


Fig. 3. Storage temperature versus time at no load condition.

found that the inner temperature of the cold chamber could reduce from 33.1 ˚C to 27 ˚C in 120 min. Coefficient of performance of the cold chamber (COP_r) was calculated. In these calculations, the properties of tomatoes were, mass = 2 kg and C_p = 3.98KJ/kg.

Theoretical COP of the system

For Module TEC1-12706

Qc = = 24.85 W

Input Power is given by,

W = 52.5 W

Theoretical COP of the system

$$COP_{th} = \frac{Qc}{W} = \frac{24.85}{525} = 0.47 \sim 0.5$$

Actual COP of the system

The temperature of the cold chamber could reduce to only 4°C by using only one thermoelectric module. Hence two thermoelectric module was used for the system.

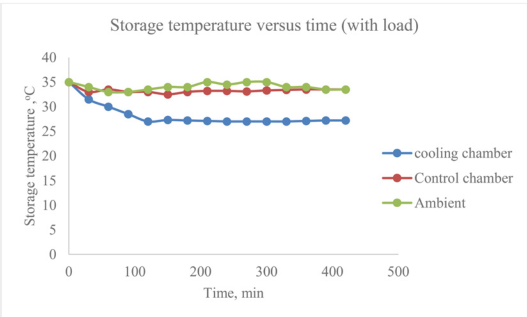


Fig. 4. Storage temperature versus time at load condition.

Table 2. Variation of temperature with time in cooling, control and ambient condition in load condition.

S. No.	Time (min)	Cooling chamber temp (°C)	Control chamber temp (°C)	Ambient Temp(°C)
1.	0	35	35	35
2.	30	31.5	33	34
3.	60	30	33.5	33
4	90	28.5	33	33
5.	120	27	33	33.5
6.	150	27.3	32.5	34
7.	180	27.2	33	34
8.	210	27.1	33.2	35
9.	240	27	33.2	34.5
10.	270	27	33.1	35
11.	300	27	33.3	35
12.	330	27	33.4	34
13.	360	27.1	33.5	34
14.	390	27.2	33.5	33.5
15.	420	27.2	33.5	33.5

COP of the cooling chamber

$$COP_R = \frac{Q_{cooling}}{W_{in}}$$

Specific heat for tomato (Cp) = 3.98 KJ/kg-°C
Mass of tomato (m) =2.0 kg
Change in temperature of the chamber= 35°C-27 °C=8 °C [reduction of approx. 8°C in 2 h
Sensible heat (Q) = m×Cp×ΔT
=2×3.98×8 =63.68 kJ
Total heat remove from the tomato =63.68 kJ

$$Qc = \frac{Q}{T} = 63.68\times1000/120\times60 = 8.844W$$

Power given to the thermoelectric module system including sink,

W_{in}= 2× V×I (Peltier module) +2× V×I (fan for sink hot side) +2×V×I (fan for sink cold side) [where V and I are the rated voltage and current respectively]
= (12×5×2+12×0.18×2+12×0.1×2)
=126.72 W

Hence, Coefficient of performance of the refrigerator (COP_r) is given by

$$COP_r = \frac{8.844}{126.72} = 0.069 = 0.07 = 0.1$$

COP of the control chamber

Specific heat for tomato (Cp) = 3.98 KJ/kg-°C
Mass of tomato (m) =2.0 kg

Change in temperature of the chamber= 35°C-32.5 °C=2.5°C [reduction of approx. 2.5°C in 2.5 hr.]
Sensible heat (Q) = m×Cp×ΔT
=2×3.98×2.5 =19.9 kJ

Total heat remove from control chamber =19.9 kJ
= 19.9×1000/150×60=2.2 W

Power given to the exhaust fan,
Win= V× I (Exhaust fan), where V and I are the rated voltage and current respectively.
= (12×0.2)
=2.4 W

Hence, Coefficient of performance of the refrigerator (COPc) is given by
(2.2/2.4) =0.9

COP of the cold chamber (refrigerator unit) is lower than conventional refrigerator. This may be the reason that the efficiency of thermoelectric modules is usually lesser than that of vapor compression system. Moreover the heat leakage through doors might reduce the efficiency of the system. However, COP of the cold chamber is more considering the energy supplied.

CONCLUSION

A thermoelectric refrigeration unit was developed using Peltier module. The test was carried out for two conditions viz., load and no load condition for both the cold and control chamber. During no load condition reduction in temperature up to 26 °C was recorded from initial temperature of 33.1°C in 6.0h when the maximum ambient temperature was recorded as 35°C. The Theoretical COP of the system was calculated as 0.5. For the load condition, 2 kg tomato was loaded in both the chamber. The reduction in temperature of tomato up to 27 °C was recorded from initial temperature 35 °C within 120 minutes for cold chamber. The actual COP of the cold chamber was 0.1 whereas that of control chamber was 0.9.

1) For no load condition, initially the temperature reduces at the faster rate from 33.1 ˚C to 29˚C. Similarly for load condition initially the temperature reduces at a faster rate from 35˚C to 31˚C. However, the time required for further reduction of temperature increased.

The possible reasons behind reduction in cooling rate are as follows:

The temperature difference between hot and cold side of PELTIER module decreased with time.

Possible losses in insulation and leakage through doors

Possible losses at the end of the junction.

2) After 12 days of storage of tomato, the percentage reduction of weight for cooling chamber and control chamber were 19.05% and 26.17% respectively.

ACKNOWLEDGEMENT

The authors acknowledge and appreciated the assistance of Ashish Kumar Singh (Student trainee).

REFERENCES

Anonymous. https://www.engineeringtoolbox.com/

Basediya A, Samuel DVK, Beera V (2013) Evaporative cooling system for storage of fruits and vegetables-a review. *J Food Sci Technol* 50(3): 429-442.

Dell EJ, Capozzi B, Xia J, Venkataraman L, Campos LM,Dhawade MB, Mourya E, Yadav A, Samuel D, Mohod SA, Deshpande VN (2015) Review on portable solar thermoelectric refrigerator cum air cooler. *Int J Adv Res Sci Engig* 4(10): 44-58.

Elsheikh MH, Shnawah DA, Sabri MFM, Said SBM, Hassan MH, Bashir MBA, Mohamad M (2014) A review on thermoelectric renewable energy: Principle parameters that affect their performance. Renewable Sustain Energy Rev 30: 337-355.

Francis O, Lekwuwa CJ, John IH (2013) Performance evaluation of a thermoelectric refrigerator. *Int J Engig Innov Technol (IJEIT) Volume* 2.

Kaymak HC, Ozturk I, Kalkan F, Kara M, Ercisli S (2010) Color and physical properties of two common tomato (*Lycopersicon esculentum* Mill.) cultivars. *J Food Agric Environ* 8: 44-46.

Lavanya G, Venkanteshwarlu S, Nagaraju A, Prasanthi G (2016) Cooling and Heating of Refrigerator Jacket by Using Peltier Effect. *Insight Mechanical Engg* 1(1): In press.

NHB (2015-16), http://apeda.gov.in/apedawebsite/six_head_product/FFV.htm

Nonoguchi Y, Ohashi K, Kanazawa R, Ashiba, K, Hata K, Nakagawa T, Kawai T (2013) Systematic conversion of single walled carbon nanotubes into n-type thermoelectric materials by molecular dopants. *Scientific Rep* 3(1): 1-7. DOI: 10.1038/srep03344.

Rawat MK, Chattopadhyay H, Neogi S (2013) A review on developments of thermoelectric refrigeration and air conditioning systems: A novel potential green refrigeration and air conditioning technology. *Int J Emerging Technol Adv Engg* 3(3): 362-367.

Rokde K, Patle M, Kalamdar T, Gulhane R, Hiware R (2017) Peltier based eco-friendly smart refrigerator for rural areas. *Int J* 7(5): In press.

Suryawanshi D, Pokale V, Pokharkar N, Walgude A, Patunkar PP (2016) Design and Fabrication of Thermoelectric Refrigerator for Liquid Cooling by Automatic Temperature Micro-Con troller. IJSTE - *Int J Sci Technol Engg* 3(1): In press.